Technical Bulletin 147 June 1941

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Accepted for Publication June 11, 1941

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SINCE BECCARI'S discovery in 1728 of the presence of gluten in wheat, the attention of chemists and cereal technologists has been attracted to this substance. Gluten is unique among the proteins. No natural food or other substance contains a nutrient material similar to it in physical properties. In fact, it might be contended that the prominence of wheat in the diet of the white races of men is due primarily to the physical properties of dough made from wheat flour, which properties are largely attributable to the presence of gluten. Elasticity and extensibility, possessed to a distinctive and singular degree by wheat flour dough, are either occasioned by the gluten, or, at least, are influenced profoundly by variations in that constituent. The nature of these properties, their measurement, and the role of gluten in effecting variations in their magnitude have been traced by the author in a recent publication (6).

Gluten is ordinarily assumed to be comprised of two general types of proteins: a prolamine known as gliadin and a glutelin known as glutenin. According to Osborne's (20) classification, collectively they constitute about 85 per cent of the total protein of flour. The recent researches of Haugaard and Johnson (11), Sandstedt and Blish (21), Blish (7), and McCalla and Gralen (15) indicate that gluten may be more complex, however. Thus Haugaard and Johnson effected a thermal fractionation of gliadin into several preparations of varying physical properties. Blish separated gluten into three groups of proteins, including a so-called mesonin fraction which appeared to be intermediate in constitution and properties between gliadin and glutenin. McCalla and Gralen, on the basis of their studies with the ultracentrifuge, find support for the earlier hypothesis that the melange is even

[1] Assistance in assembling the wheat protein data constituting the basis of this study was furnished by the personnel of Work Projects Administration, Official Project No. 65-1-71-140, Subproject No. 464. Sponsor: University of Minnesota.

more complicated and "that the gluten protein is a protein system made up of components varying regularly and systematically in chemical and physical properties."

In addition to these gluten proteins Osborne identified an albumin (leucosin), a globulin, and a proteose among the simple proteins of the wheat kernel, although the presence of a proteose has been disputed by other workers and is not generally assumed to be at all prominent. In addition, certain tissues of the wheat kernel, notably the germ or embryo, contain nucleo-proteins. The amount in the entire kernel is not large, however, since the proportion of embryo tissue is small, and the endosperm contains little of the nucleo-protein.

D. Breese Jones (13, 14) and associates have shown that there are differences between the endosperm proteins and proteins of the same general classes in the pericarp of wheat. However, it is not the purpose of this bulletin to trace these distinctions in detail, nor yet to discuss at length the significance of these proteins in terms of the physical properties which they influence or the technological uses of wheat products in which they are involved. Numerous workers, particularly among the Americans, have demonstrated the relationship between protein content and baking quality. Nor is it contended that variations in the baking strength of wheat flours are determined solely by their protein content. Other factors may exert a distinct influence upon baking behavior; moreover, there are undoubtedly some differences among the gluten proteins from different wheat samples, as determined by (a) genetic factors, as between different wheat species and varieties, (b) the environment in which the wheats were grown, (c) biological maturity at the time of harvest, (d) duration and conditions of storage of the wheats and flours, and (e) possibly some other factors or combinations of them.

It seems probable that there is a greater uniformity in gluten properties among the hard wheats of the Great Plains area of North America than in any other major wheat growing region of the world. For several decades the wheat breeders of this region have had a fairly definite objective in terms of technological properties, and have "tailored" their new varietal productions to a common pattern. In the hard spring wheat belt, Scotch Fife and its hybrid offspring, Marquis, were long regarded as possessing fairly ideal milling and baking qualities. New varieties distributed in this area were compared with Marquis in recent years, and those which were grown extensively were rather similar to it. In the hard winter wheat region Turkey Red became the standard type from the technological standpoint, and the new high quality hybrid varieties were both related to it and similar in milling and baking properties. To be sure, some varieties have been grown in both areas that did not meet these specifications, but, generally speaking, they were transitory types in the long-time program of quality wheat production. Moreover, they usually can be identified by skilled wheat buyers and accorded appropriate treatment in merchandising.

It follows, therefore, that when the wheat of a large area is fairly homogeneous either as to genetic origin or characteristics, a chemical criterion of quality, such as protein content, is more significant and valid than when a considerable number of widely varying types of wheat are grown. Undoubtedly this has had a large bearing upon the uses that have been made of protein content as an index of quality, and has been a marketing factor in the merchandising of the hard wheats of the Great Plains area.

Another consideration, no doubt, has been the comparative ease and accuracy with which protein determinations can be made. The Kjeldahl method and its modifications so commonly employed in America lend themselves to large scale operations. Thus in certain of the larger wheat markets there are laboratories which can handle many hundreds of such determinations every day. Moreover, the determinations can be made with celerity, and often only an hour or two elapses from the receipt of the sample until the result of the analysis is available. The determination, in the hands of well-trained analysts, is a reasonably accurate one; apparently the actual errors of determination lie within the same range as the sampling errors. Small samples are sufficient; in fact, the test itself requires only 2 grams for duplicate determinations, and micro methods are available which can be applied to a small fraction of that quantity when limited material is available. If desired, the test can be applied to whole or unground wheat kernels, but it is usual to grind the wheat first, in the interest of more accurate sampling. Obviously, it is less easy to find 30± wheat kernels that truly represent the average of a wagon-, car-, or ship-load, than it is to find 100 times that number of kernels to constitute a more generous sample for grinding. Moreover, the ground material can be weighed out to within a milligram of the standard charge for analysis, say 1 gram, which is not true when entire or unground kernels are used. In the latter instance a separate calculation must be interposed with each sample, to correct for the known variation in the weight of the charge.

INFLUENCE OF ENVIRONMENT ON THE COMPOSITION OF WHEAT

It has long been known that wheat responds, in terms of composition, to variations in its physical and chemical environment. The investigations along this line conducted prior to 1925 were reviewed at some length by the author (5), and will not be repeated here. In general it appeared that varying rainfall induces substantial variations in the protein content of wheat. Moist, cool summers result in large, plump, soft wheat kernels that are low in protein, whereas hot, dry summers tend to result in relatively high protein wheat. The latter conditions are characteristic of much of the Great Plains area in which hard wheats are grown in America. However, the operation of any factor which tends to increase the available nitrogen of the soil is reflected in an increased protein content. The application of nitrates or ammonium salts, or cultural practices which build up or retain soil nitrates operate in the direction of an increased nitrogen- or protein-content of the crop.

The whole problem of climate, and its relation to the succession of chemical and biological events in the soil on the one hand, and the other direct or indirect effects upon plant growth and plant metabolisms is exceedingly complex. It is not easy to sort out the individual factors of climate and trace their effect upon the plant and the composition of its fruits. It is still more difficult to combine these several factors, properly weighted, into a single mathematical expression or formula that can be used as a basis for predicting either the size of the crop or its composition. Accordingly, we are still forced to deal with broad generalities in this connection.

The author (3), in Minnesota Agricultural Experiment Station Bulletin No. 131, arranged the wheat samples collected in 16 counties of the state in order of rainfall from April 1 to September 1 (crop season 1911) in the counties in which they were grown. There was an evident trend in the direction of a decreasing protein content with an increasing precipitation during these five months, although the correlation was not perfect by any means. Using averages, the crude protein in the flour milled from these wheats decreased regularly from an average of 13.47 per cent in the instance of samples grown in the counties where the rainfall (April 1-September 1) averaged between 12 and 14 inches, to 11.73 per cent in the counties receiving 20 to 22 inches of rainfall during the same period. Like experiences have been reported from several American states and numerous areas in Europe. In a later portion of this bulletin reference will be made to the observed relationship between precipitation in the Northwest during an extended succession of 14 crop seasons, and the protein content of the wheat crops marketed during those seasons.

KERNEL TEXTURE AND PROTEIN CONTENT

In this same connection reference should be made to the relationship between the relative vitreousness or hardness of wheat kernels and their protein content. Nowacki (19) emphasized that the difference in visual appearance of "mealy" (also known elsewhere as "yellow berry," "starchy," "soft") and "horny" (or "vitreous," "flinty," "corneous," "dark," "hard") wheat kernels is due to the presence of more air spaces in the former. This view was accepted by Häckel (10) who also mentioned that the corneous grains are richer in protein than mealy kernels of the same variety. In view of the relation between the relative volume of air space and vitreousness, it developed that the vitreous kernels also have a higher specific gravity than the mealy kernels. This was discussed at some length by the author in an earlier publication (4).

Snyder (24) separated starchy and vitreous kernels with the results shown in table 1.

This same general observation was also made by numerous other workers, and it naturally followed that rough approximations of the relative protein content of wheat were made by noting the appearance and vitreousness of samples under observation. In fact, the division of the hard spring, hard winter, and durum wheat classes into subclasses under the Federal standards for wheat promulgated in 1916 was occasioned, no doubt, by the relationship between the percentage of vitreous kernels and the protein content. The issue then arose as to how accurate a basis was afforded for the prediction of protein content from the per-

Table 1. Crude Protein in Starchy and Dark (Vitreous) Wheat Kernels. Snyder, 1904

	Protein, per cent
Miscellaneous samples	
Starchy kernels	12.68
Dark (vitreous) kernels	15.33
Selected seed wheat	
Starchy kernels	12.83
Dark (vitreous) kernels	14.93

centage of vitreous kernels. Certain difficulties are apparent at once to those familiar with this problem. Thus, one may encounter a series of kernels which are wholly vitreous in each instance, and yet there may be considerable range in the protein content of the several kernels. Again, a kernel is not always wholly soft or starchy. A fraction of the endosperm may be vitreous, giving rise to the condition variously described as "mottled," "sub-corneous," or "piebald." This presents the problem of how to classify such kernels: whether to sort and weigh them with the wholly soft or starchy kernels, or to include them among the vitreous grains. Accordingly, the manual fractionation or sorting of the kernels may not be expected to provide a wholly adequate basis for predicting protein content of wheat.

As an increasing volume of data became available for testing this relationship, computations of the correlation between these two variables began to appear in the literature. Mangels and Sanderson (17) reported the coefficients of correlation between the protein content and the percentage of dark, hard, and vitreous kernels in the instance of samples collected from the 1922, 1923, and 1924 spring wheat crops in North Dakota recorded in table 2. In a later publication Mangels (16) added equivalent data for the 1925 crop. These coefficients are also recorded in table 2.

The correlation was significant but low in 1925, fairly high in 1924, considerably higher in 1922, but small and not significant in 1923. Mangels commented that the percentage of vitreous kernels was not an adequate basis for the accurate prediction of protein content.

Shollenberger and Coleman (22) separated several samples of hard red spring, hard red winter, and durum wheats into dark, mottled, and starchy kernels, respectively, and analyzed each fraction separately. There was a tendency toward a regular decrease in protein content in progressing from the dark to the starchy fractions. The data for these eight samples follow:

Crude protein (N x 5.7), per cent, in:

Type of kernel	Hard spring			Hard winter			Durum	
	7006	7066	7276	7005	7154	7489	7401	7402
Dark	14.39	11.78	11.63	11.78	10.70	13.66	12.09	11.49
Mottled	9.86	9.71	9.32	10.21	8.18	13.02	10.01	10.01
Starchy	8.82	9.86	8.09	9.22	7.49	....	8.87	8.93

The same trend was observed in the flour samples milled from these eight wheat samples after the latter were fractionated into three types of kernels.

Shollenberger and Kyle (23) computed the gross correlation coefficient of wheat kernel texture (as percentage of dark, hard, and vitreous kernels) and crude protein content in the instance of 1,290 samples of hard red spring wheat of the 1915 to 1923 crops and found $r = +0.536 \pm 0.013$. This is of about the same order as the average of Mangels' and Sanderson's data for the 1922 and 1924 North Dakota spring wheat crops, but distinctly greater than the latter's 1921 and 1925 crop data.

Coleman, Dixon, and Fellows (8) reported the correlation between the percentage of dark, hard, and vitreous kernels and protein content of both hard red spring and hard red winter wheats of the crops of 1923 and 1924 with the results shown in table 2. In the instance of the crop of 1923, the relationship is much more precise than was reported by Mangels for the North Dakota spring wheats of the same season.

Newton, Cook, and Malloch (18) computed the correlation between the percentage of vitreous kernels and protein content in a collection of hard wheats, and found $r = +0.24 \pm 0.09$. The scatter diagram of these data suggests a curved relationship. In this series the protein content of the "starchy" kernels ranged from 10.4 to 17.9 per cent. The latter is an unusually high protein percentage for starchy kernels; in fact, it is well above the average for the vitreous kernels of many samples. This must complicate the usefulness of the vitreous kernel percentage as a basis of prediction and tend to minimize it.

Aamodt and Torrie (1) reported an extended study of the relation between kernel texture and various factors of quality in spring wheat. While the correlation between protein content and kernel texture was not high, as shown by their data in table 2, they actually encountered a better relationship between kernel texture and baking quality than between the latter and protein content.

Waldron (25) pointed out that Mangels worked with a complex of samples, including many which evidently had been affected in starchiness and bushel weight by shriveling, due to rust and to weathering. Accordingly, Mangels' data might not be comparable to the more refined study conducted later by Waldron, in which the problem was rendered more simple by restricting the study to samples involving only variety and environment as variables and not affected appreciably by disease. Among these samples the correlation between protein content and percentage of yellow berry was $r = -0.706$. The regression of protein content on percentage of yellow berry was -0.16; thus a 10 per cent positive deviation in yellow berry would be associated, generally, with about a 1.5 per cent negative deviation in protein content. Waldron also recorded a fairly large correlation of $r = +0.549$ between the percentage of yellow berry and the plumpness of the spring wheat kernels.

Wheeting and Vandecaveye (26) reported a relatively high correlation, $r = -0.790 \pm 0.019$ between the percentage of yellow berry and protein content in winter wheat grown in Washington during the crop seasons 1921-29. This correlation was computed by a special method employing arithmetical progression in establishing classes as developed and employed by Gaines and Smith (9). Since this procedure was not followed by the researchers whose data are recorded in table 2, the coefficient of correlation was recomputed by conventional mathematical methods. The resulting value $r = 0.693$ was recorded in the table to afford a more consistent comparison with the other data.

Moreover, the general appearance of the graphic array of their data suggests a curvilinear relationship between protein content and yellow berry, approaching an asymptote as the yellow berry content falls below 20 per cent, and the protein content exceeds 11.5 per cent. In other words, the percentage of yellow berry kernels approaches and remains close to zero as the protein content rises above 11.5 per cent, and, accordingly, there is practically no correlation between these variables when the percentage of protein is above an 11.5 per cent minimum.

Table 2. Correlations of Percentage of Vitreous (or of Starchy) Kernels and Protein Content of Wheat as Reported by Several Investigators

Investigators and Citation Number*		Class of wheat	Crop year	Number of samples	r =	
Mangels and Sanderson	(16)	HRS	1922	90	0.660	±0.041
Mangels and Sanderson	(16)	HRS	1923	199	0.067	±0.047
Mangels and Sanderson	(16)	HRS	1924	316	0.453	±0.030
Mangels	(15)	HRS	1925	436	0.299	±0.043
Shollenberger and Kyle	(23)	HRS	1915-23	1,290	0.536	±0.013
Coleman, Dixon, and Fellows	(8)	HRS	1923	128	0.641	±0.035
Coleman, Dixon, and Fellows	(8)	HRS	1924	113	0.398	±0.054
Coleman, Dixon, and Fellows	(8)	HRW	1923	183	0.600	±0.032
Coleman, Dixon, and Fellows	(8)	HRW	1924	76	0.559	±0.053
Newton, Cook, and Malloch	(18)	HRS	1924	49	0.24	±0.09
Aamodt and Torrie	(1)	HRS	1931	61	0.410	±0.075
Aamodt and Torrie	(1)	HRS	1931	88	0.447	±0.058
Aamodt and Torrie	(1)	HRS	1932	26	0.588	±0.046
Aamodt and Torrie	(1)	HRS	1933	12	0.675	±0.089
Waldron	(25)	HRS	1932	75	0.706	±0.039
Wheeting and Vandecaveye	(26)	Winter	1921-29	158	0.693†	±0.019

* Number refers to the citations given at the end of the bulletin.

† The value 0.790 recorded in Washington Agricultural Experiment Station Bulletin 344 was computed by a special method employing arithmetical progression in establishing classes as developed and employed by E. F. Gaines (see Jour. Amer. Soc. Agron. 25, 273-284. 1933).

The heritable nature of kernel texture was demonstrated by Aamodt and Torrie (1) as well as by other workers, but it is also true that large variations in this characteristic of the grain can be induced by varying the environment of the growing plant. Because of the observed general relationship between protein content and kernel texture it may be assumed that those environmental factors which affect the former will influence the latter as well.

APPLICATION OF PROTEIN TESTING TO WHEAT MERCHANDISING

About the time of the World War flour mills began to classify and store their wheat on the basis of protein content. A few grain elevators also instituted a practice of sorting and binning wheats, and later selling large lots on a protein basis. Premiums for high protein content began to be offered by active bidders for quality wheat, and improved laboratory facilities were provided for analyzing the grain. The force of this new factor in merchandising influenced grain inspection departments to add protein laboratories to their equipment, the first such laboratory being opened in Portland, Oregon, in 1921. The Minnesota Grain Inspection Department installed laboratories at Minneapolis and Duluth in time to be used in marketing the crop of 1925.

In the Minnesota inspection of wheat it became the practice to report the protein content of each car load on the grain inspection ticket, although this factor of quality was not involved in determining the actual *grade* of wheat. Samples were also analyzed by laboratories either attached to grain commission firms or engaged by them for the purpose. In addition the purchaser, often a flour mill or elevator, made a third analysis. In the event of a failure of the buyer and seller to agree upon the protein content when this factor was involved in fixing the price or acceptance of the parcel of wheat, a fourth or referee sample might be subjected to analysis by a disinterested commercial laboratory.

Protein testing became so extensive during the decade from 1921-1930 that several large, well-equipped laboratories conducted a thriving business in these Midwestern grain markets. It was estimated that as many as 5,000 individual protein determinations were made in a single day incidental to marketing wheat in the Minneapolis area alone during periods of heavy wheat receipts.

Apparently all of the official and commercial laboratories engaged in protein testing have uniformly employed the factor Nitrogen x 5.7 in converting the percentage of ammonia nitrogen distilled from the acid digest in the Kjeldahl determination into terms of protein. This is the factor specified in the official method for determination of protein in flour of the Association of Official Agricultural Chemists (2). While this factor may not be as nearly scientifically accurate for wheat as it is for flour, as emphasized by Jones (12), who proposed the factor N x 5.83 for the former, it is convenient to use the same factor for both wheat and flour. In this publication the factor N x 5.7 was applied in computing all the protein data here recorded.

PROTEIN DISTRIBUTION OF SPRING WHEAT

The data used in preparing the charts and making the computations involving spring wheat that are included in this bulletin were taken from the records of the Minneapolis office of the Minnesota State Grain Inspection Department. In the instance of the eight crops of 1925 to 1932, inclusive, the cars of grain arriving in the Minneapolis terminals had been classified by point of origin. This resulted in recording the protein content of each lot of grain inspected under the name of the shipping point, and hence the state where it was grown. Wheat shipped from certain border stations near a state line may have been mislabeled at times, due to having been hauled over the line for shipment. Such instances are not sufficiently common, however, to affect substantially the general accuracy of the averages by states, and more particularly since samples from just across a state line will not differ greatly in composition from the wheat grown on contiguous areas of the adjoining state.

It is our understanding that the compilation of the inspection data by shipping points for the eight crop seasons of 1925-1932 resulted from the interest and activities of the late R. A. Wilkinson, who was employed by the State Railroad and Warehouse Commission. After his death this particular activity lapsed, and, apparently, has not been resumed by the Commission. Accordingly, the protein data for the crops of 1933 to 1938 inclusive, as recorded here, are not segregated by states.

All of the hard spring wheat data involved in the preparation of this bulletin were taken off the records of the State Grain Inspection Department by clerks detailed by the Work Projects Administration, and a portion of the analysis and organization of the data was done by the same staff.

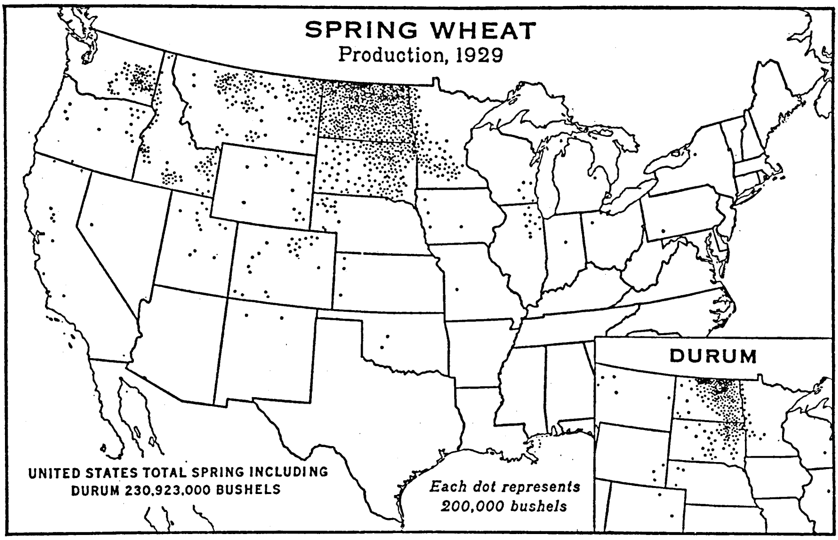

FIG. 1. SPRING WHEAT PRODUCTION MAP FOR THE 1929 CROP, REPRODUCED FROM U. S. D. A. MISC. PUB. 267, "A GRAPHIC SUMMARY OF FARM CROPS," BY O. E. BAKER AND A. B. GENUNG

The general areas from which the hard spring wheat is drawn that flows into Minneapolis are suggested by the spring wheat production map of 1929 in figure 1. This shows graphically those portions of Minnesota, North and South Dakota, and Montana which produce considerable quantities of such wheat, and it may be assumed that the wheat included in these studies came from those areas.

For convenience, the crop year was considered to begin with the receipts of September 1, and to extend through August 31 of the following year. Of course there is some error in this assumption, but it is the conventional procedure in this market and about the best that can be done. It is not possible to determine from the records which is new crop and which old crop wheat as received during several weeks immediately after the beginning of the harvest. Again, the error is not apt to be large enough to affect the analyses attempted in the present instance.

Figure 2 includes four curves representing the percentage of the 1925 crop shipped from Minnesota, North Dakota, South Dakota, and Montana, and marketed through Minneapolis, Minnesota, that was included in each of the protein categories. The latter represented a range of 0.5 per cent of protein in each instance; thus all the samples containing between 9.5 and 9.99 per cent of protein were included in the first category or group, etc. The median point of this group, namely 9.75 per cent, was assumed to be the average of the group as well.

All the protein data thus recorded in these distribution curves are on the basis of "as received" moisture content; that is, they are not corrected to a constant moisture basis. The average percentage of moisture in the spring wheat of each crop is recorded in table 3, except in the instance of the crop seasons of 1925, 1931, and 1936, when acceptable data were not available. Obviously, correcting the data to a constant moisture basis, say 13.5 per cent, would have the effect of shifting the curves for the crops of 1932 to 1938 to the left, i.e., the apparent percentages of protein would be reduced appreciably. That is not the manner in which the data are treated in merchandising wheat, however, and, accordingly, they are handled here as they are reported in the grain inspection records, and used by the grain trade, namely, "as received," or uncorrected to a constant moisture basis.

It is evident that the Minnesota and North Dakota spring wheats of the 1925 crop were similar in protein content. The South Dakota wheats averaged somewhat higher, although there was considerable overlapping in the range from 11 to 13 per cent. Montana spring wheats were outstandingly higher in their protein content; however, a considerable percentage of the crop contained in excess of 14 per cent of protein, whereas very little of the wheat from Minnesota and the Dakotas contained more than 14 per cent.

The average protein content of the wheats from each of these states is recorded in table 3. Also in figure 10 appears the distribution curve for all samples of spring wheat of this and the three succeeding crops. From the shape of the curve, as well as from the standard deviation of the individual analyses recorded in table 3, it is evident that the variability of protein content was fairly large during 1925. In other words, no large percentage of the crop was encountered in any one protein category when the latter represented a range of 0.5 per cent. In 1925 this was the consequence, in no small measure, of the high protein content of the Montana shipments.

The data for 1926, recorded graphically in figure 3, present an interesting contrast with those of the preceding season. In the instance of the spring wheats grown in Minnesota and the Dakotas, the spread of the protein content was greater than in 1925. For example, a considerable percentage of the spring wheat marketed from North Dakota and South Dakota during the 1926

Table 3. Average Percentages of Protein in Spring Wheat Marketed Through Minneapolis, Minnesota, by Crops

	Minnesota		North Dakota		South Dakota		Montana		All spring wheat			
Crop Year	No. of samples	Average protein	No. of samples	Average protein	No. of samples	Average protein	No. of samples	Average protein	No. of samples	Average protein	Standard deviation σ	Average moisture content
		Per cent		Per cent		Per cent		Per cent		Per cent		Per cent
1925	6,609	11.90	17,204	11.22	3,694	12.47	5,739	14.30	33,246	12.49	1.34	....
1926	7,051	12.47	11,716	13.19	1,886	14.02	5,492	14.26	26,145	13.28	1.55	13.7
1927	6,075	11.70	31,323	11.82	13,365	12.26	13,181	12.14	63,944	11.96	0.78	13.2
1928	4,280	12.46	24,974	12.23	6,745	12.69	13,965	12.60	49,964	12.42	0.77	13.4
1929	4,737	12.05	19,400	13.75	8,422	13.65	4,643	15.30	37,202	13.70	1.41	13.4
1930	6,710	12.95	29,532	14.75	9,938	15.50	5,869	15.80	52,041	14.85	1.47	13.1
1931	4,370	14.00	9,939	15.20	2,776	15.66	97	16.88	17,182	15.00	1.22	....
1932	5,237	13.87	24,802	14.11	12,661	14.12	2,327	15.10	45,027	14.21	0.99	11.7
1933	....	....	....	....	....	....	....	....	23,829	15.03	0.89	11.5
1934	....	....	....	....	....	....	....	....	12,900	14.80	1.04	11.4
1935	....	....	....	....	....	....	....	....	28,544	15.30	1.71	11.8
1936	....	....	....	....	....	....	....	....	16,698	15.92	1.64	....
1937	....	....	....	....	....	....	....	....	12,185	14.83	1.28	11.6
1938	....	....	....	....	....	....	....	....	13,169	13.78	1.04	11.5

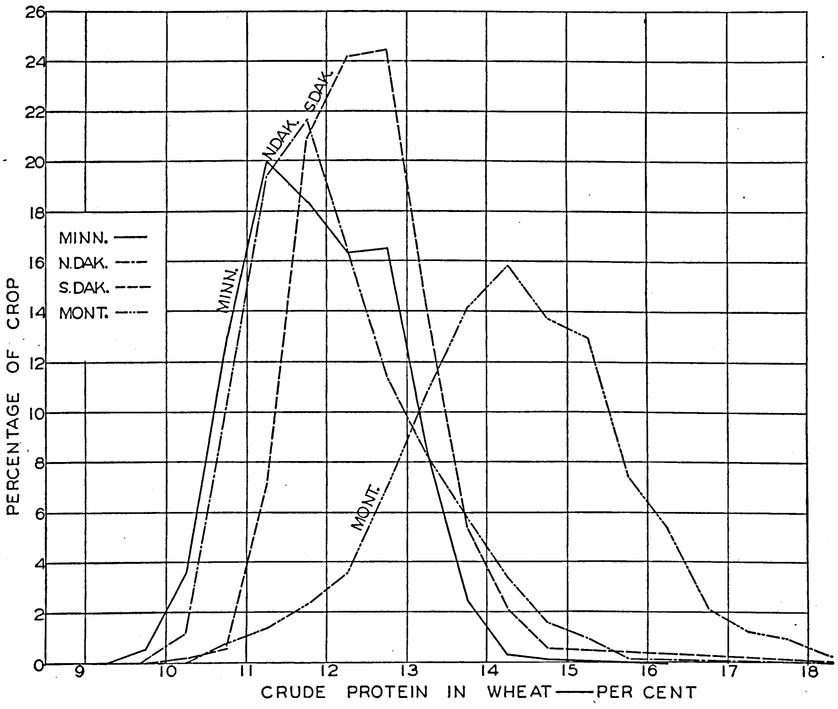

FIG. 2. DISTRIBUTION CURVES SHOWING THE PERCENTAGE OF THE 1925 HARD SPRING WHEAT CROP GROWN IN MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA, AND MONTANA AND MARKETED THROUGH MINNEAPOLIS, MINNESOTA, THAT FELL INTO EACH PROTEIN CATEGORY

crop season contained in excess of 14 per cent protein, which was not true in 1925. The results of this spread in protein content, commonly stated statistically as a large standard deviation, are graphically indicated in figure 10, where all the spring wheats marketed in 1926 are included in a single, broad distribution curve. The average protein content for the season is fairly high, 13.28 per cent, and the standard deviation, as recorded in table 3, is the largest for the ten-year period from 1925 to 1934, inclusive.

The spring wheats of the 1927 and 1928 crop seasons have so many characteristics in common, insofar as protein content is concerned, that they may be discussed collectively. While the average protein content in 1928 was about 0.5 per cent higher than in the preceding season, the type of distribution is practically the same. The spreads of the curves, as recorded in figures 4 and 5, are small, and the standard deviations, as entered in table 3, are the lowest of any of the 14 seasons under consideration. In

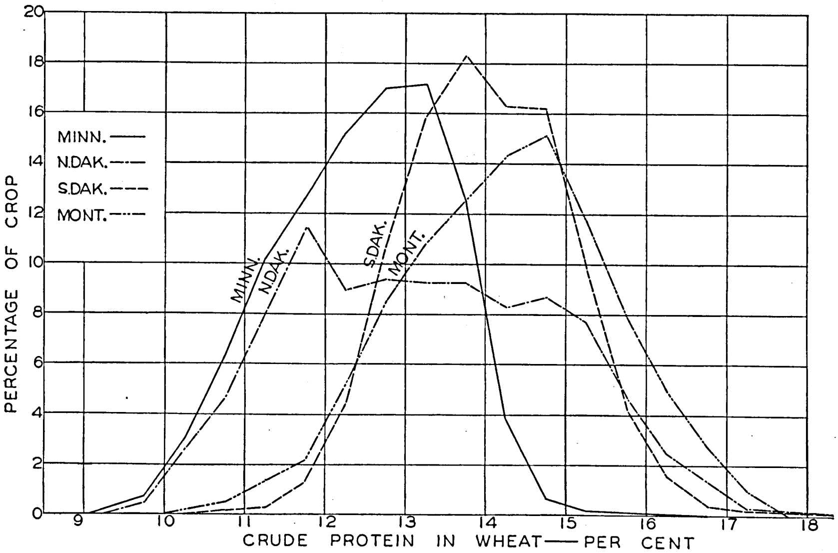

FIG. 3. DISTRIBUTION CURVES SHOWING THE PERCENTAGE OF THE 1926 HARD SPRING WHEAT CROP GROWN IN MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA, AND MONTANA AND MARKETED THROUGH MINNEAPOLIS, MINNESOTA, THAT FELL INTO EACH PROTEIN CATEGORY

fact, it seems doubtful as to whether or not these characteristics are apt to be manifested by more than a small proportion of spring wheat crops. It is even more significant that the average protein content by states is more uniform than normal; this might be made more emphatic by calling attention to the relatively small difference in protein percentage between the wheats from the eastern and western portions of the spring wheat area. A discussion of the possible reasons for these peculiarities appears in a later section of this bulletin. It is true that the 1928 crop graded somewhat higher than was the case in 1927, as shown by the higher percentage grading No. 2 or better, recorded in table 4, despite the lower rainfall in 1928. This may be a reflection, in part, of the stem rust epidemic conditions prevailing in 1927.

The plumpness of the wheat kernels in these four spring wheat crops was normal, as indicated by the average weight per bushel recorded in table 4. There was some variation, to be sure, the 1925 crop being significantly lower than the 1928 crop, which latter was the best in that regard of any of the 14 crops from 1925 to 1938. The standard deviation of the weight per bushel was also fairly low during these four seasons of 1925, 1926, 1927, and 1928, being 1.170, 1.639, 1.974, and 1.537, respectively. This is also demonstrated by the graphs in figure 16.

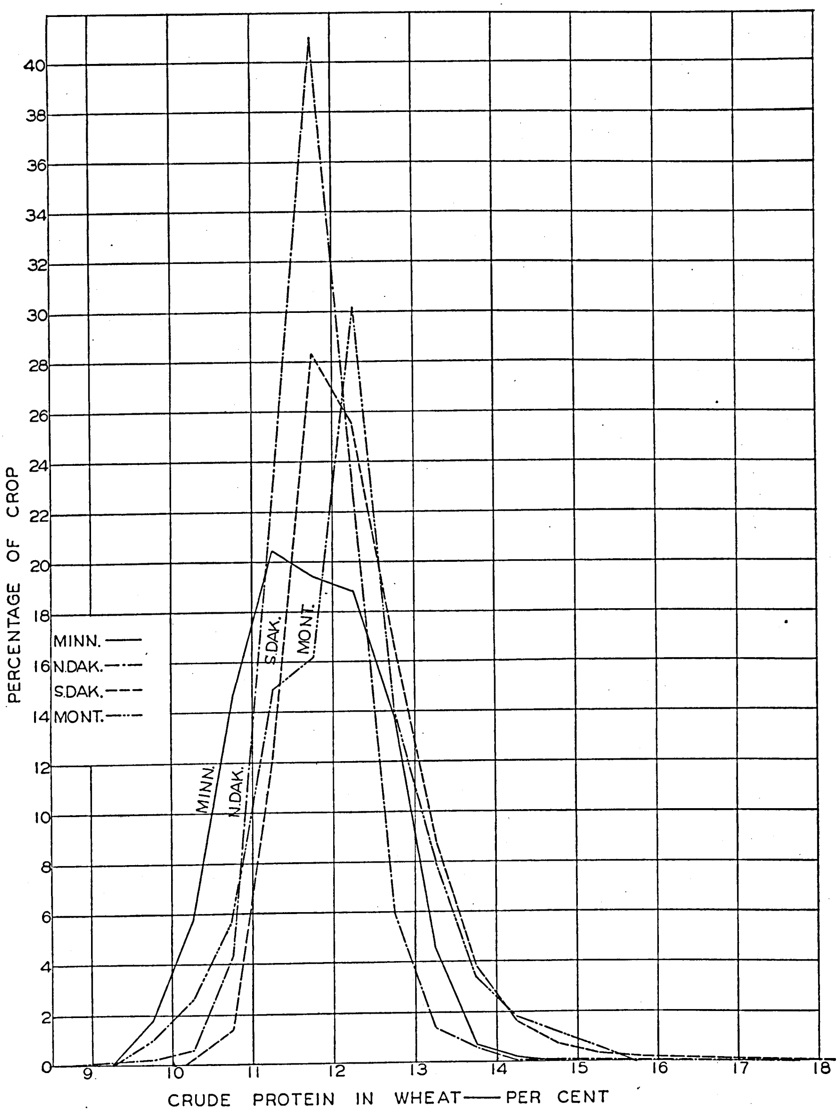

FIG. 4. DISTRIBUTION CURVES SHOWING THE PERCENTAGE OF THE 1927 HARD SPRING WHEAT CROP GROWN IN MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA, AND MONTANA AND MARKETED THROUGH MINNEAPOLIS, MINNESOTA, THAT FELL INTO EACH PROTEIN CATEGORY

In 1929 the distribution curves by states, shown in figure 6, assume a more normal pattern. In progressing from the eastern to the western portions of the area, there is a distinct trend toward an increasing percentage of high protein wheat. When all the data are combined in one distribution curve for the season, as

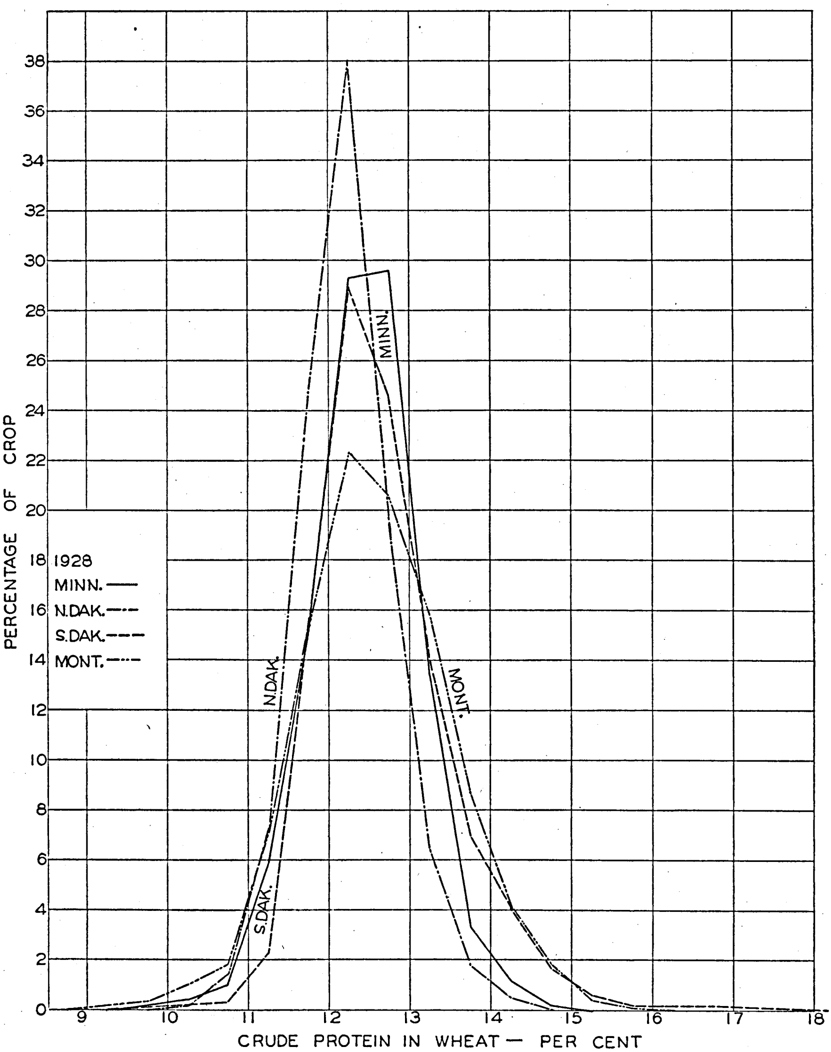

FIG. 5. DISTRIBUTION CURVES SHOWING THE PERCENTAGE OF THE 1928 HARD SPRING WHEAT CROP GROWN IN MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA, AND MONTANA AND MARKETED THROUGH MINNEAPOLIS, MINNESOTA, THAT FELL INTO EACH PROTEIN CATEGORY

recorded in figure 11, the result is a fairly broad curve, with not more than about one sixth of the crop in any single protein category. Somewhat the same condition maintained in 1930 (Fig. 7), except that the general level of protein percentage was higher, which shifted the distribution curves to the right. In fact, the crop of 1930 entered what might be called the high protein decade, from which high level spring wheat has not yet

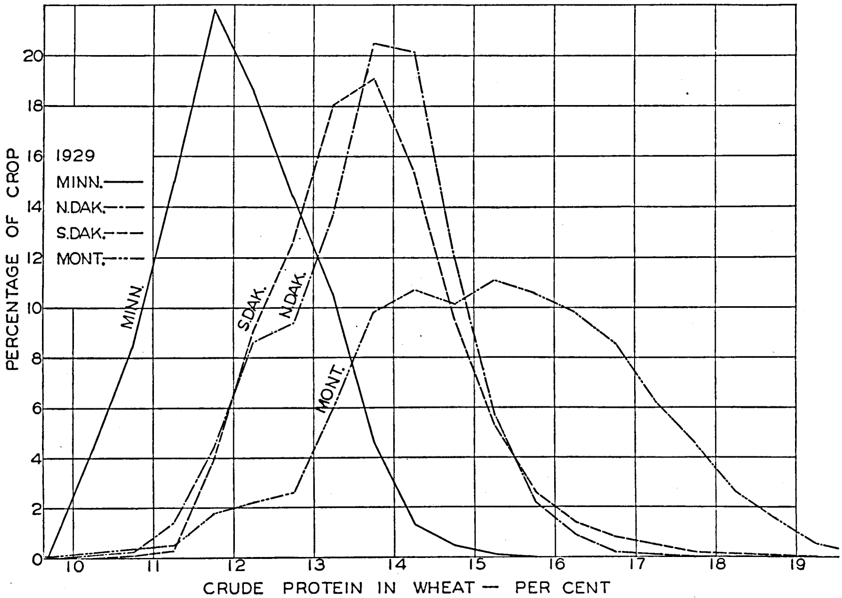

Fig. 6. Distribution Curves Showing the Percentage of the 1929 Hard Spring Wheat Crop Grown in Minnesota, North Dakota, South Dakota, and Montana and Marketed through Minneapolis, Minnesota, That Fell into Each Protein Category

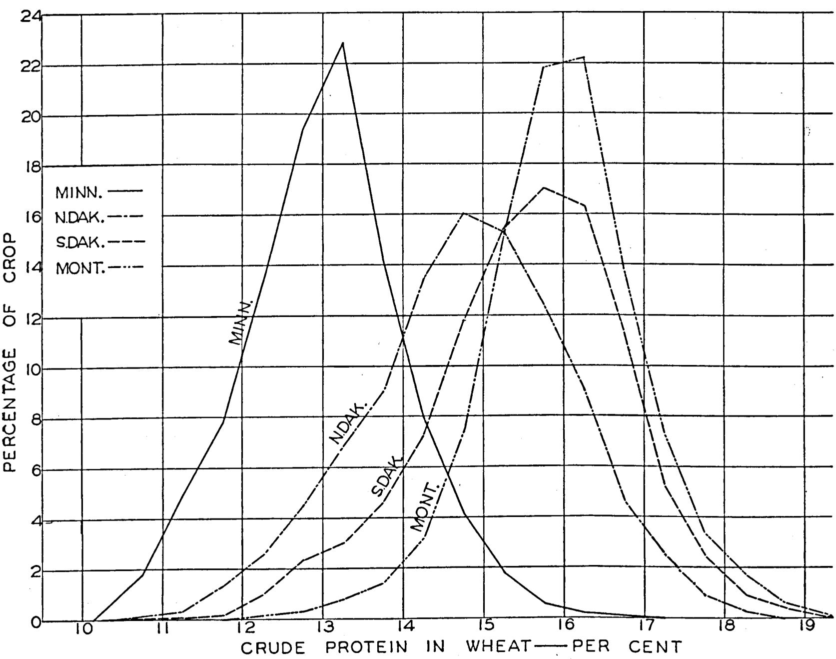

Fig. 7. Distribution Curves Showing the Percentage of the 1930 Hard Spring Wheat Crop Grown in Minnesota, North Dakota, South Dakota, and Montana and Marketed through Minneapolis, Minnesota, That Fell into Each Protein Category

Table 4. Statistics of Spring Wheat (Excluding Durum) Production in the Four States of Minnesota, North Dakota, South Dakota, and Montana, Crops of 1925 to 1938

Crop Year	Acreage seeded, 1,000 acres	Acreage harvested, 1,000 acres	Production 1,000 bushels	Average yield per acre	Wheat grading No. 2 or better in Minneapolis	Average weight per bushel	Average protein content	Rainfall—wheat districts
				bushels	per cent	lbs.	per cent	inches
1925	....	13,020	140,106	10.8	67.5	58.0	12.49	18.05
1926	....	11,553	103,779	9.0	65.7	58.7	13.28	16.39
1927	....	12,504	178,147	14.3	69.1	58.6	11.96	22.31
1928	....	12,068	178,012	14.7	80.1	59.4	12.42	18.52
1929	....	13,431	128,285	9.6	79.9	58.5	13.70	16.40
1930	....	13,593	142,612	10.5	58.7	57.1	14.85	16.92
1931	....	8,788	60,439	6.9	56.2	57.3	15.00	15.06
1932	....	15,169	179,489	11.8	72.8	57.6	14.21	18.26
1933	....	13,235	96,239	7.3	90.0	59.0	15.03	14.82
1934	13,852	6,006	45,640	7.6	63.2	58.7	14.80	12.29
1935	16,968	12,959	94,230	7.3	12.4	49.9	15.30	18.98
1936	16,621	6,246	38,415	6.1	16.3	54.3	15.92	11.63
1937	15,916	10,785	88,409	8.2	24.5	53.4	14.83	18.21
1938	16,656	14,086	148,828	10.6	35.9	55.3	13.78	18.19

Production data from Yearbooks of the U. S. Department of Agriculture.
Rainfall data taken from reports of the U. S. Weather Bureau.
Protein data from the author's records.
Wheat grades from the reports of the Minnesota Grain Inspection Department.
Weights per bushel supplied by the General Field Headquarters of Federal Grain Supervision, Agricultural Marketing Service, U. S. Department of Agriculture.

fully emerged. Also this was the first critical drouth year, since the rainfall for the area, though slightly greater than in 1929, to be sure, was still inadequate, and the cumulative effects of two successive dry years began to be felt. The result was a tapering off of kernel plumpness, as registered in the weight per bushel, as well as in the percentage of the spring wheat grading No. 2 or better, as recorded in table 4. Thin wheat continued to appear in the market wheat through 1931 and 1932.

In 1931 the distribution curves again arranged themselves from left to right, as shown in figure 8, in progressing from the eastern to the western portions of the spring wheat area. One notable feature of the 1931 crop data is the small variability of the limited Montana car receipts, over four fifths of which contained between 16 and 18 per cent of protein. The number of cars shipped from Montana to Minneapolis was very small (97), and the wheat production of that state was very low, being only about 25 per cent of the five-year average from 1924-28. In fact, the four-year succession of dry seasons in Montana from 1928 to 1931 resulted in a progressive reduction in wheat production which, in terms of the five-year average from 1924-28, was reduced to 71 per cent of that level in 1929, 61 per cent in 1930, 25

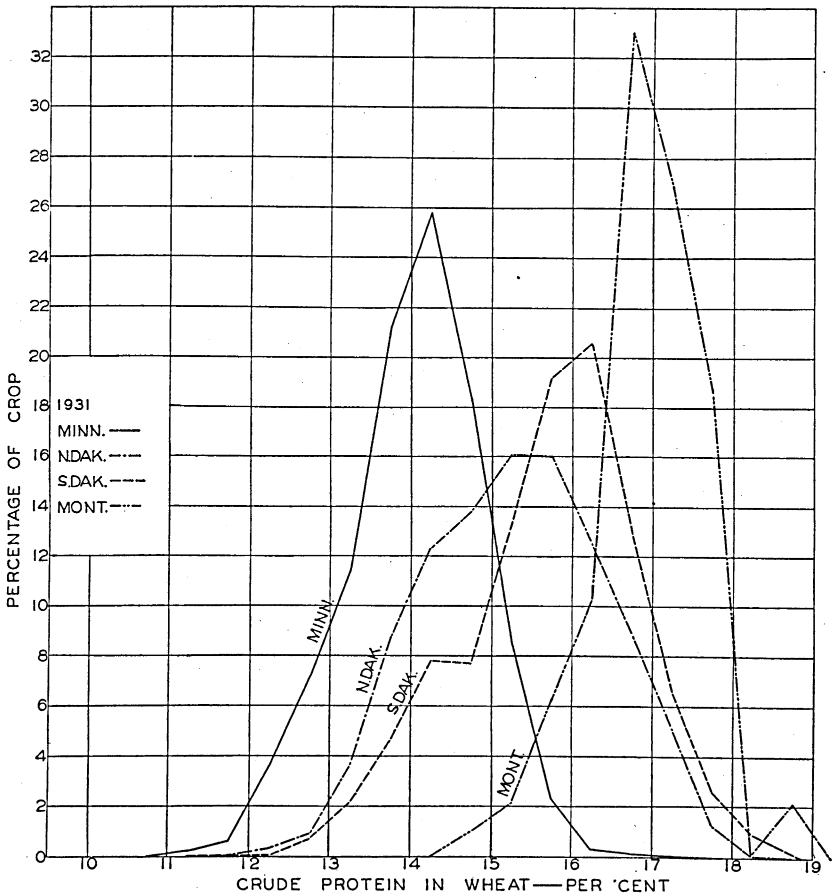

FIG. 8. DISTRIBUTION CURVES SHOWING THE PERCENTAGE OF THE 1931 HARD SPRING WHEAT CROP GROWN IN MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA, AND MONTANA AND MARKETED THROUGH MINNEAPOLIS, MINNESOTA, THAT FELL INTO EACH PROTEIN CATEGORY

per cent in 1931, and practically returned to the five-year average in 1932 when rains were more abundant.

The picture in 1932 (Fig. 9) involved another change, being more like 1925, except that the general level of protein content was appreciably higher. As in 1925, there was no great difference in the average protein content or distribution curves of the wheats shipped from Minnesota or Dakota points, but the Montana samples tended to contain considerably more protein. In terms of the 14-season study, this crop represented a slight recession from the high protein level of the two preceding crops and the five crops which followed it.

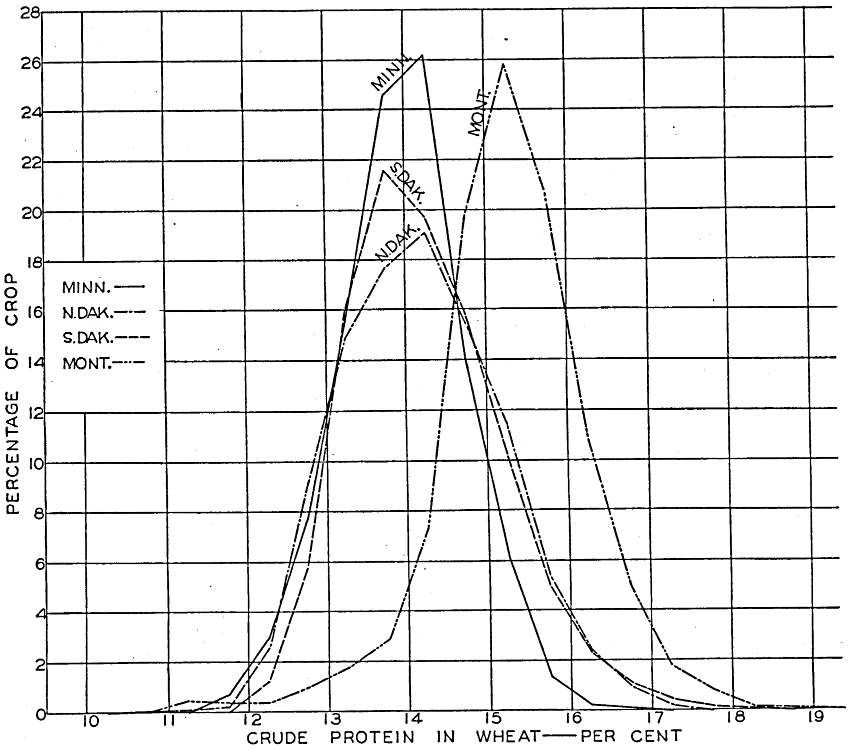

FIG. 9. DISTRIBUTION CURVES SHOWING THE PERCENTAGE OF THE 1932 HARD SPRING WHEAT CROP GROWN IN MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA, AND MONTANA AND MARKETED THROUGH MINNEAPOLIS, MINNESOTA, THAT FELL INTO EACH PROTEIN CATEGORY

Beginning with the crop season of 1933, the protein data were no longer segregated by points of shipment, and, accordingly, it was not possible to continue the presentation of protein distribution curves by states. All of the spring wheat receipts were assembled by seasons in single curves, however, and these are presented in figure 12 for the seasons 1933 to 1938, inclusive. The wheat marketed during the four seasons 1933, 1934, 1935, and 1937 had many points of similarity insofar as protein content alone was concerned. The averages and the standard deviations of 1933 and 1934 came close to being identical. The average protein content of the 1935 crop was only slightly greater, but the standard deviation was high. This resulted from the skewed curve, which disclosed a considerable number of samples with an exceptionally high protein content. This curve was nearly the mirror image of the 1936 protein distribution curve, being skewed to the right, i.e., in the direction of high protein content, while

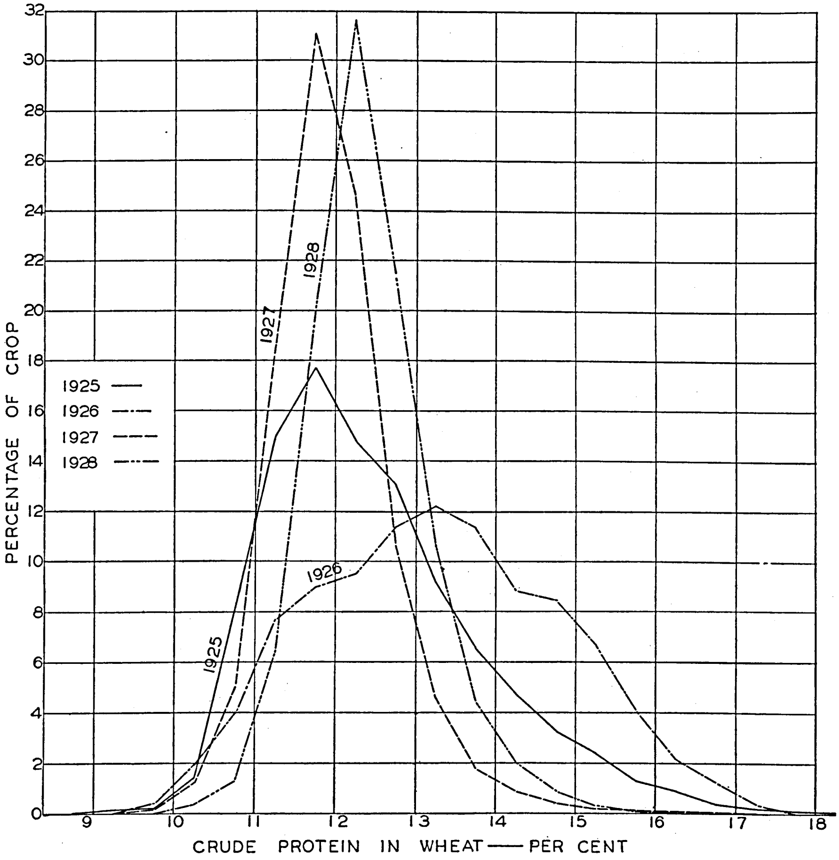

FIG. 10. DISTRIBUTION CURVES SHOWING THE PERCENTAGES OF ALL HARD SPRING WHEAT, CROPS OF 1925, 1926, 1927, AND 1928 AND MARKETED THROUGH MINNEAPOLIS, MINNESOTA, THAT FELL INTO EACH PROTEIN CATEGORY

the latter was skewed to the left. The poor quality of this 1935 crop spring wheat, as disclosed by the low grades and the very low average weight per bushel, indicated by the data in table 4, has been attributed generally to the severity of the stem rust epidemic of that season. Much wheat was heavily discounted at the peak of the marketing season early in the crop year because of low test weight per bushel. Moreover, there was a large variability in the weight per bushel of the 1935 crop spring wheat, the standard deviation being 5.715.

The 1936 crop protein distribution curve was the most distinctive of the 14 here presented. Its average value, 15.92 per cent, was doubtless the highest of any crop in recent years. This was the season of severe drouth combined with exceptionally high temperatures, which resulted in a short wheat crop of very unusual properties. Cereal technologists attached to the spring wheat mills have a vivid recollection of the problems involved in using this wheat. Protein content was a less adequate criterion of baking properties than at any time in a score of years. There were indications that the heated atmosphere surrounding the wheat plants growing in a dry soil effected a premature desiccation of the plant tissue before the normal process of maturation could occur. This appeared to result in the presence of incompletely synthesized gluten proteins, which, in turn, failed to confer those physical properties upon the dough that would be anticipated from the presence of the percentage of nitrogenous compounds indicated by chemical analysis. No chemical or physical tests were then available which could be used in lieu of baking tests, and the latter merely indicated abnormalities without disclosing exactly what was wrong. It was generally agreed, however, that any gain in protein content which was occasioned or accompanied by the physical and other properties characterizing this crop of 1936 was not to be desired, and the spring wheat milling industry was vastly relieved when the next crop returned to a more nearly normal level of chemical and technological properties.

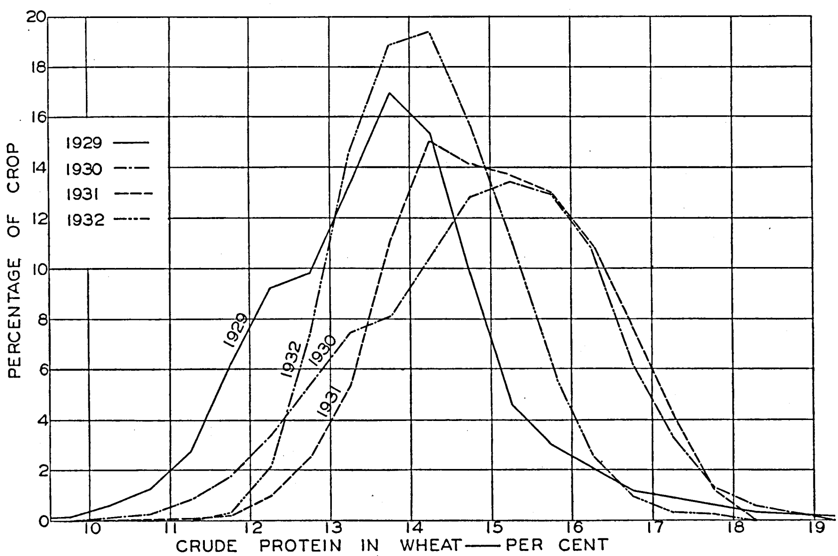

FIG. 11. DISTRIBUTION CURVES SHOWING THE PERCENTAGES OF ALL HARD SPRING WHEAT, CROPS OF 1929, 1930, 1931, AND 1932 AND MARKETED THROUGH MINNEAPOLIS, MINNESOTA, THAT FELL INTO EACH PROTEIN CATEGORY

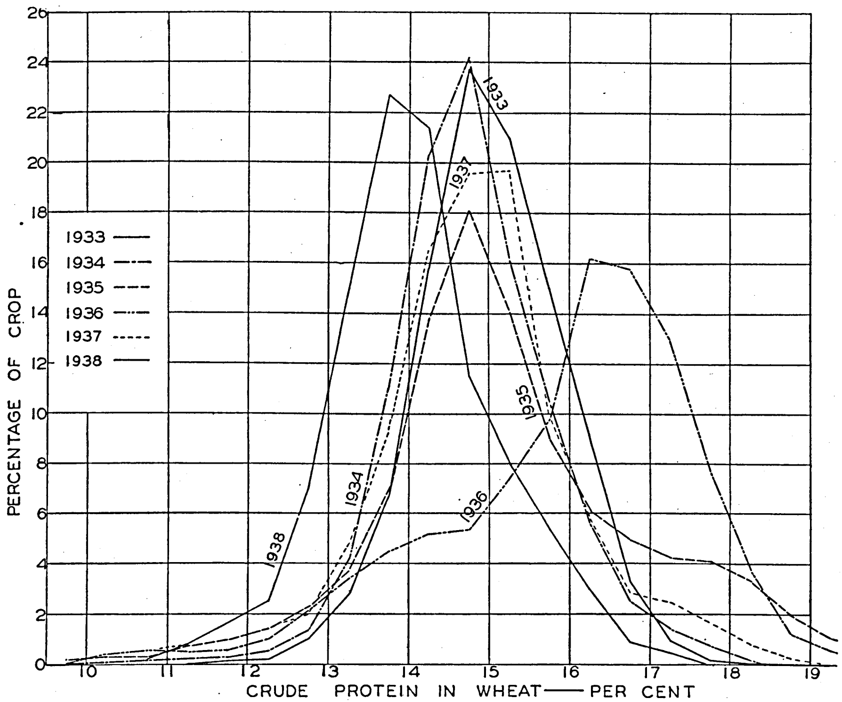

Fig. 12. Distribution Curves Showing the Percentages of All Hard Spring Wheat, Crops of 1933, 1934, 1935, 1936, 1937, and 1938 and Marketed through Minneapolis, Minnesota, That Fell into Each Protein Category

The 1937 crop of spring wheat possessed, more or less, the characteristics of the 1933 and 1934 crops insofar as protein content alone was concerned, although the market grades and weights per bushel were lower. The rust epidemic in 1937, while not as severe as in 1935, may have contributed to the observed reduction in the quality of the crop. This effect was complicated, in all probability, by a carry-over of the severe drouth conditions of the previous season, with the result that only one fourth of the spring wheat inspected in Minneapolis graded No. 2 or better.

The protein distribution curve of the 1938 crop moved still farther toward the left, as disclosed by the lower average protein content. The curve was skewed somewhat to the right, although not to the same degree as in 1935, and the standard deviation was the same as in 1934. The 1938 crop was also rather low in average weight per bushel, although there was an upward trend in this characteristic from 1935 to 1938.

RELATION OF CLIMATE AND WHEAT COMPOSITION

No single attribute of the complex which we call *climate* is highly correlated with wheat composition, but, in general, rainfall is rather prominent in its relation to protein content in the instance of the hard wheats produced in this area. Certain data have been tabulated, and appear in table 4, to afford a basis of comparison. This records, in the last two columns, the weighted average rainfall in the principal wheat producing districts of the four spring wheat states, and the average protein content. The average weight per bushel, and the percentage of the wheat of each of the several crops that grade No. 2 or better, are also shown. Likewise the table gives the acreage harvested and yield of grain by crops, and the acreage seeded and harvested is also recorded in figure 13. More detailed rainfall data by states are recorded in table 5.

On scanning these data it appears that an average precipitation of 16 ± inches represents a critical range in wheat production and composition. Thus, in 1926 when the rainfall approached 16 inches, the average yield per acre fell to 9.0 bushels and the average protein content rose significantly. The heavier precipitation of 1927 and 1928 operated in the reverse direction. While the rainfall was actually lower in 1928 than in 1927, there appears to have been a carry-over of the effect of the heavier 1927 rains, as registered in average yield per acre, as well as in general quality and higher grades assigned the spring wheats marketed in Minneapolis in 1928.

In 1929 the rainfall was distinctly deficient, the average yield per acre fell below 10 bushels, and the protein content reached

Table 5. Precipitation in Selected Portions of the Spring Wheat Area Weighted in Terms of Wheat Production

Year	Minnesota	North Dakota	South Dakota	Montana	All four states
	inches	inches	inches	inches	inches
1925	23.11	18.93	16.04	15.40	18.05
1926	19.30	15.35	18.45	13.20	16.39
1927	24.53	21.83	22.98	20.50	22.31
1928	22.83	18.96	19.44	13.46	18.52
1929	18.31	13.94	21.22	12.63	16.40
1930	21.68	16.26	19.10	11.62	16.92
1931	19.71	15.42	16.20	9.63	15.06
1932	21.48	17.84	18.65	15.98	18.26
1933	16.83	13.60	16.12	13.43	14.82
1934	14.14	10.79	14.90	9.90	12.29
1935	26.53	20.40	19.51	10.51	18.98
1936	14.53	9.50	13.67	10.09	11.63
1937	25.87	17.67	19.47	11.69	18.21
1938	23.30	15.78	19.85	16.81	18.19

a new high level of 13.70 per cent. Since 1930 was also rather dry, the accumulated deficiency of precipitation raised the protein content still higher, in fact, to the highest level for many years. The 1931 season was still drier, and the result is clearly evident in yields, composition, and grading. A small acreage was harvested, accompanied by a substantial abandonment of acreage, as shown by the graphs in figure 13.

In 1932 the precipitation rose to a more nearly normal level, with substantial effects upon acreage harvested, average yield per acre, and grading quality. The protein content fell to a lower average than the two preceding seasons. The following season (1933) the rainfall once more dropped below the critical point, and the average yield per acre was reduced to the low value of 7.3 bushels. The protein content rose somewhat, the average being practically identical with that of 1931.

In 1934 occurred one of the most serious drouths experienced up to that time in the history of spring wheat production in this area. Over half the acreage was abandoned and on the small acreage finally harvested the average yield was only 7.6 bushels per acre. The average protein content of the spring wheat marketed in Minneapolis was not as high as might have been expected from these climatological conditions, however, and the quality of the crop in terms of average weight per bushel and grades was fairly high. This may have been the result of the

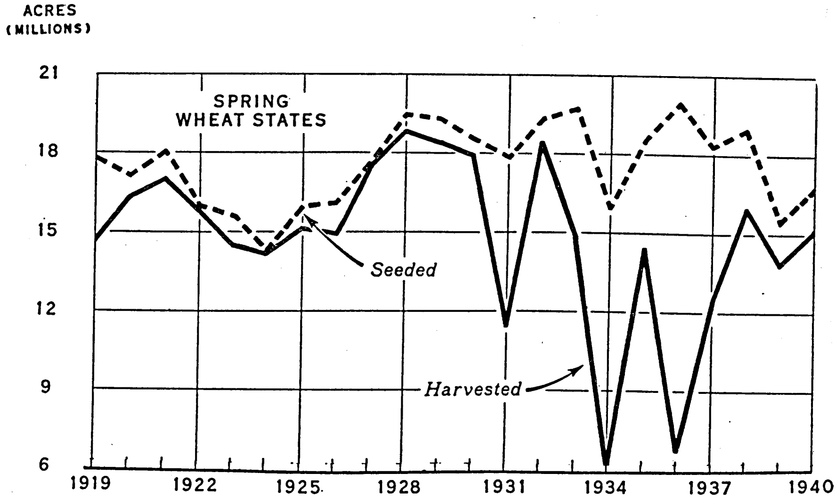

FIG. 13. SPRING WHEAT ACREAGE SEEDED AND HARVESTED IN THE UNITED STATES DURING THE PERIOD FROM 1919 TO 1940 (COPIED FROM A MIMEOGRAPHED DOCUMENT, "REGIONAL ADJUSTMENTS TO MEET WAR IMPACTS," PUBLISHED BY THE U. S. D. A., OCTOBER, 1940)

abandonment of more than half the acreage, and the consequent elimination of much of the thinner wheat.

While 1935 was not such a dry season the accumulated effects of the preceding dry years, beginning with 1929, exerted an influence. A much larger acreage was harvested than in 1934, but the yield per acre of the crop was still low. Also the average protein content rose to a new high of 15.30 per cent.

In 1936 the extreme drouth was complicated by abnormally high temperatures, and the result was the smallest wheat crop for many years. Its market quality was low, as evidenced by the small percentage grading No. 2 or better and its low average weight per bushel. Reference has already been made to its peculiar technological properties. The high protein content afforded scant consolation to the millers who attempted to convert it into flour of satisfactory baking qualities.

As in 1935, there was a carry-over of these 1936 climatic abnormalities into the following crop season. If the drouth of 1936 (and possibly also of 1934, for that matter) had not been so severe, the average rainfall of 18.2 inches in 1937 might have been sufficient to mature a normal crop. As it was, the yield was only a little over 8 bushels per acre on the acreage harvested; there was an abandonment of about one third of the seeded acreage; and the protein content continued at an exceptionally high level. In 1938 the more abundant rainfall began to make itself effective in terms of decreased abandonment, a large production, higher yields per acre, and the normal accompaniment of these crop characteristics, a lower protein content.

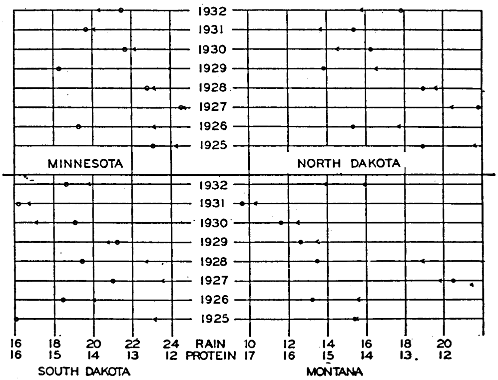

FIG. 14. RAINFALL IN INCHES AND PROTEIN CONTENT IN PER CENT OF THE CROPS FROM 1925 TO 1932 IN MINNESOTA, NORTH DAKOTA, SOUTH DAKOTA, AND MONTANA

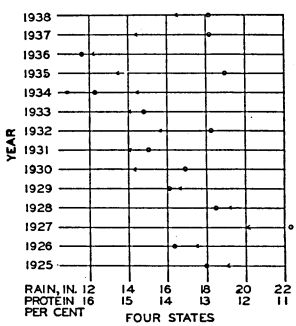

FIG. 15. RAINFALL IN INCHES AND PROTEIN CONTENT IN PER CENT OF THE CROPS FROM 1925 TO 1938 IN THE SPRING WHEAT AREA

An effort has been made to depict these rainfall-protein relationships graphically in a series of figures (Fig. 14) in the instance of the eight crops from 1925 to 1932, inclusive, during which period the data were segregated by states. The rainfall, recorded by a circle, is represented by an ascending scale from left to right; the protein content, shown at the tip of the arrow, is represented on a scale which descends from left to right. This inversion of

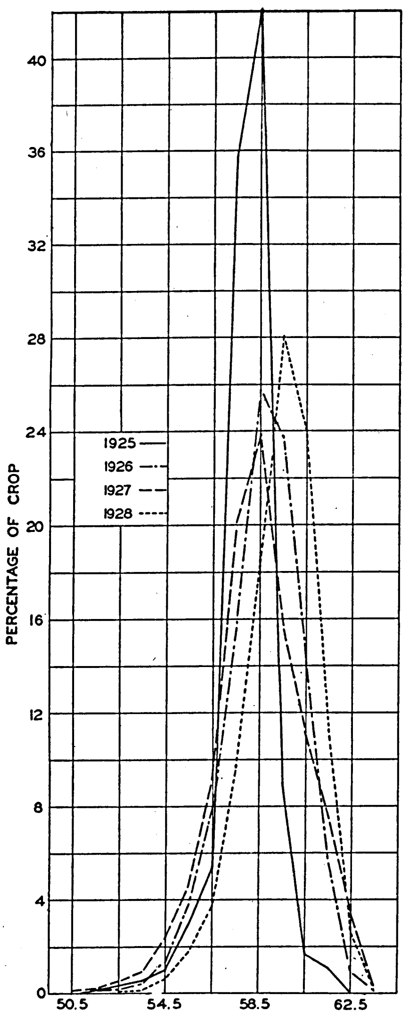

Fig. 16. Distribution Curves of the Weight per Bushel of the 1925, 1926, 1927, and 1928 Hard Red Spring Wheat Crops

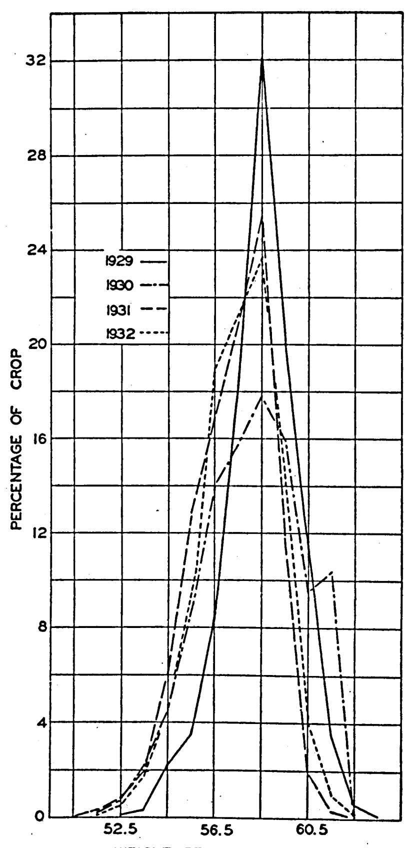

Fig. 17. Distribution Curves of Weight per Bushel of the Hard Spring Wheats of the 1929, 1930, 1931, and 1932 Hard Spring Wheat Crops

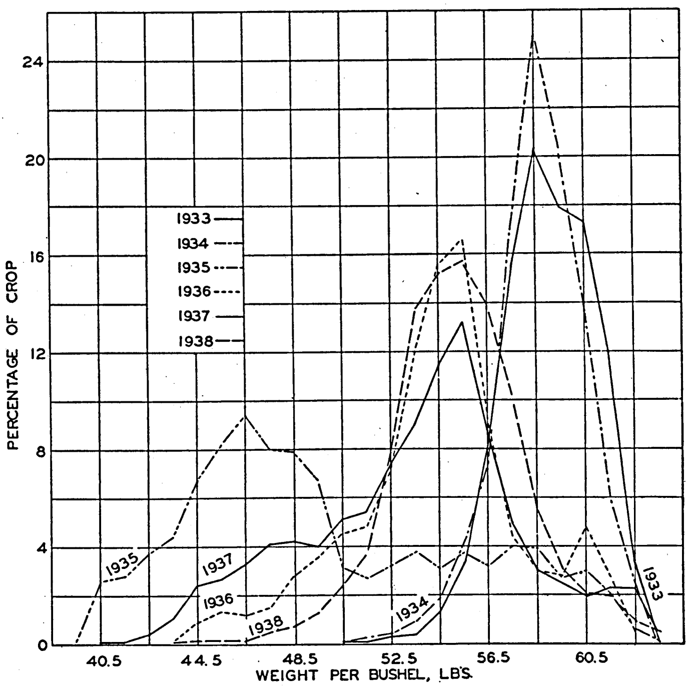

FIG. 18. DISTRIBUTION CURVES OF WEIGHT PER BUSHEL OF THE HARD SPRING WHEATS OF THE 1933 TO 1938 HARD RED SPRING WHEAT CROPS

the normal convention is employed to facilitate demonstrating the increase in protein content which tends to accompany decreasing precipitation. If the relationship were simple and uniform, a graph could be devised in which the two points regularly coincide. For reasons already emphasized, this does not follow, however. Not only the complexities of climate itself but also the effect of one season upon the next result in a correlation of annual rainfall with protein content that is far from perfect.

Referring to the records for the four states combined in figure 15, it appears that the dry conditions of 1926 resulted in a higher protein content the next year than might have been anticipated from the rainfall of 1927. The progressively diminishing precipitation of 1928 and 1929 registered in a higher protein content in 1930 than might have occurred had there not been the sequence of dry years. In 1932, likewise, the increased precipitation had less effect than the equivalent rainfall of 1928, which followed a moist season. Then came another sequence of seasons of progressively diminishing rainfall in 1933 and 1934, with the result that the approach to normal precipitation in 1935 did not register in terms of the decrease in protein that would be normal to a 19 inch average rainfall. The occasion for the high average protein content of the 1936 crop is fully apparent, and, in light of foregoing comments, the retarded movement of protein content toward a lower average in 1937 and 1938 is explained.

The detailed data for the four states, through the seasons of 1925-1932, inclusive, may be worked out in a similar manner. The Minnesota sequence is most difficult to explain, particularly the 1929 data. Obviously either the precipitation data do not represent what actually occurred on the fields where the wheat grew, or some factors other than rainfall were operative during that season in influencing the protein content.

Since the effect of climate is registered in terms of weight per bushel as well as in terms of protein content, the distribution curves of weight per bushel for the 14 crops of hard spring wheat from 1925 to 1938 are recorded in figures 16, 17, and 18. The average weight per bushel of these crops of spring wheat was tabulated in table 4. Data employed in plotting these curves were provided through the courtesy of the Agricultural Marketing Service, United States Department of Agriculture. Such data are compiled annually in the General Field Headquarters, Chicago, Illinois, and include all hard spring wheat marketed in the United States. Thus the curves in these three figures are not confined to hard spring wheat marketed through Minneapolis, but it is doubtful as to whether the latter would differ substantially from the entire crop. At any rate, they afford a graphic picture of the variability within a crop, and the differences between crops over a period when this characteristic of wheat might be expected to vary through wide limits.

PROTEIN DISTRIBUTION IN THE SPRING WHEAT SUBCLASSES OF DARK NORTHERN SPRING AND NORTHERN SPRING

Reference has already been made to the relationship of vitreousness of wheat kernels to their protein content. In the Federal standards for wheat it is provided that samples with more than 75 per cent of dark, hard, and vitreous kernels shall be classified as *dark northern spring*, whereas when the percentage of such kernels is less than 75 per cent and more than 25 per cent the sample shall be classified as *northern spring*. In addition a third subclass is provided, to include wheat samples in which less than 25 per cent of the kernels are dark, hard, and vitreous.

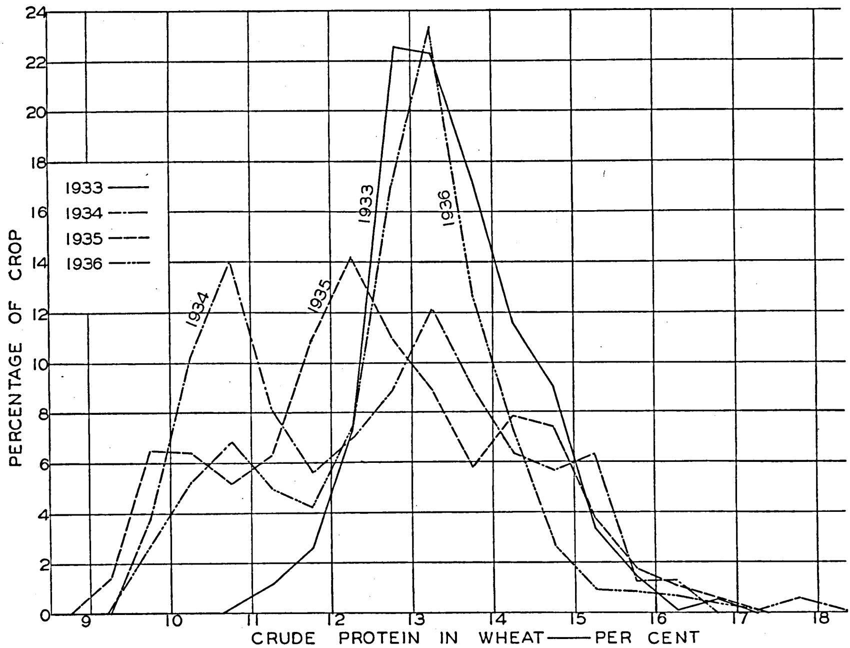

FIG. 19. DISTRIBUTION CURVES SHOWING THE PERCENTAGE OF THE WHEATS GRADED AS NORTHERN SPRING, CROPS OF 1933 TO 1936, THAT FELL INTO EACH PROTEIN CATEGORY

Presumably the intent in providing hard wheat subclasses based upon relative vitreousness is to effect an approximate segregation on the basis of relative protein content and/or baking strength.

To test the adequacy of this system of classification as an index of protein content, the spring wheats inspected in Minneapolis during the four crop seasons of 1933-36, inclusive, were segregated by subclasses, and protein distribution curves were plotted for the dark northern and northern spring wheats, respectively. The resulting graphs are included in figure 19 for northern spring and figure 20 for dark northern spring. The average percentages of protein in these subclasses and the number of inspection samples are recorded in table 6. Evidently the dark northern wheats predominated in the four seasons involved, as might be anticipated in view of the high average protein content of the wheats grown and marketed during those years. The number of northern spring wheat samples is large enough to be representative, however.

As might be expected, the averages of protein content of the dark northern spring wheat samples are considerably higher than of the northern spring wheats. In 1936, which was the season of severe drouth and high temperatures, the difference was

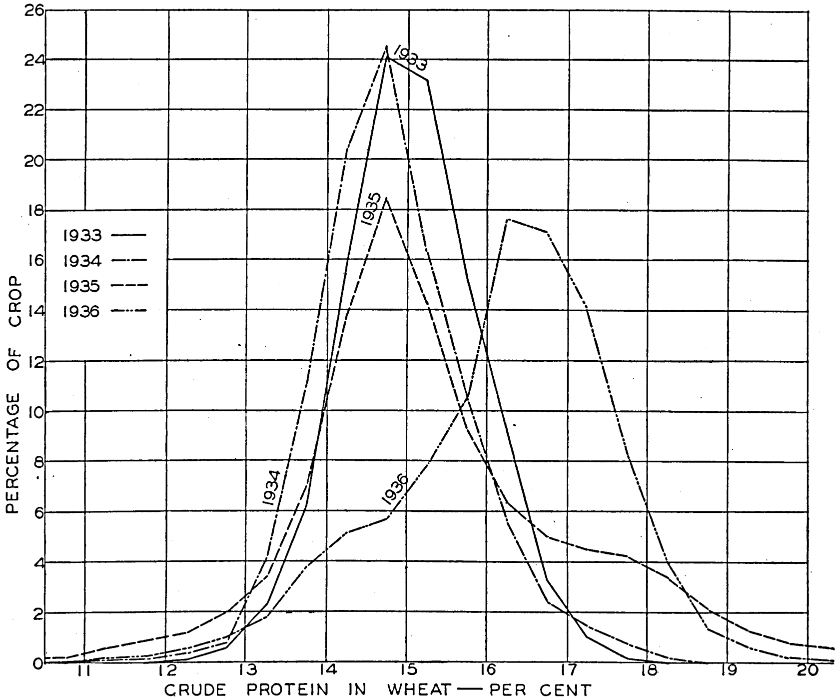

Fig. 20. Distribution Curves Showing the Percentage of the Wheats Graded as Dark Northern Spring That Fell into Each Protein Category

greatest, being about 4.3 per cent. The least difference, among these four crops, was in 1933 when it was only 1.6 per cent.

Averages are only part of the story, however. Equally significant is the extent of overlapping between the two subclasses in terms of protein content. In 1933 it would appear that 14 per cent of protein is a convenient level on which to base these comparisons. Thus 74.6 per cent of the northern spring wheat contained less than 14 per cent of crude protein, while only 9.2 per cent of dark northern spring contained less than 14 per cent.

The computation in the instance of the 1934 spring wheat crop

Table 6. Average Protein Content, and Number of Inspection Samples Analyzed, of Dark Northern Spring Wheats, and Northern Spring Wheats Marketed Through Minneapolis, Minnesota, in 1933, 1934, 1935, and 1936

Crop year	Dark northern spring: Number of samples	Dark northern spring: Average protein content	Northern spring: Number of samples	Northern spring: Average protein content
		Per cent		Per cent
1933	23,261	15.06	568	13.46
1934	12,743	14.82	157	12.49
1935	27,871	15.37	673	12.57
1936	6,314	16.21	537	11.89

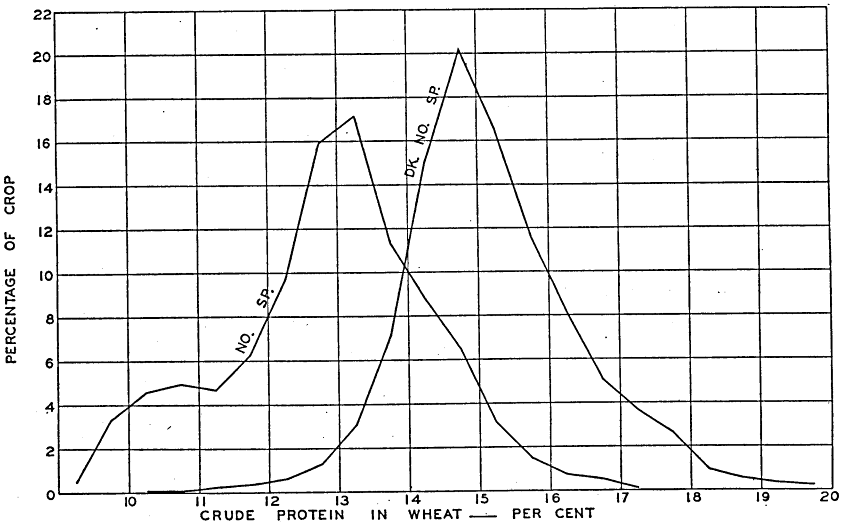

FIG. 21. DISTRIBUTION CURVES SHOWING THE PERCENTAGES OF THE WHEATS OF THE COMBINED CROPS OF 1933, 1934, 1935, AND 1936 GRADED AS NORTHERN SPRING AND DARK NORTHERN SPRING THAT FELL INTO EACH PROTEIN CATEGORY

is a little more involved, because of the bimodal form of the protein distribution curve for the northern spring wheat. If the level of the cutoff is moved down to 13.5 per cent crude protein, then 70 per cent of the northern spring, and only 6.3 per cent of the dark northern spring contain less than that percentage of protein; 71 per cent and 8.5 per cent, respectively, in 1935, and 72.4 per cent and 3.56 per cent in 1936. When all four crops are pooled, then it appears that 78.4 per cent of the northern spring wheat contained less than 14 per cent crude protein, and only 13 per cent of the dark northern wheat was below that level.

To simplify this comparison further, the data for the four seasons were combined in two curves representing the distribution of protein in the dark northern spring and northern spring wheat subclasses, respectively, and these are included in figure 21. The overlapping area represents 36 per cent of the northern spring wheat samples, and a like percentage of the dark northern spring wheat samples, or 18 per cent of the combined area of both distribution curves. If this overlapping area is divided along the vertical line represented by about 14.1 per cent of crude protein, the two resulting portions will be of equal size or area. This suggests that, in the instance of these four crop seasons, 14.1 $\pm$ per cent of protein constituted a critical level of protein in determining the classification of spring wheat into the two subclasses involved here. Accordingly, in the instance of individual wheat samples in that range of protein content the chances were approximately equal that they would be graded in either of the two subclasses. While the odds in favor of being classified as dark northern spring wheat increased rapidly as the protein content increased above 14.1 per cent of protein, to be sure, the possibility of being included in the northern spring wheat was still present even when the protein content exceeded 16 per cent.

It thus appears that a fair degree of separation in terms of protein content has been effected by this system of grading hard spring wheat into subclasses on the basis of relative vitreousness of the samples, although the separation is far from precise. If a flour mill or elevator purchased a sufficient number of lots of each subclass, and pooled and mixed the lots of each subclass separately, the two composite lots thus resulting could be expected to have a decidedly different average protein content. This difference would not be constant from season to season, however. If only occasional car lots were purchased, however, then there would be a chance that the parcels of each subclass would not differ appreciably in protein content.

VARIABILITY OF RECEIPTS FROM INDIVIDUAL SHIPPING POINTS

Since the shipping point of wheats graded and analyzed by the Minneapolis office of the State Grain Inspection Department was recorded in the instance of the receipts during the crop seasons from 1925 to 1932, it appeared desirable to make use of these records in computing the relative variability of the protein content of wheat shipments from individual shipping points. Accordingly, certain of the protein data were organized by points of origin, that is, under the name of the station from which they were shipped, and when ten or more cars were shipped from a station, the coefficient of variation (C.V.) of shipments from that station was computed. The coefficient of variation in this instance is the standard deviation (σ) divided by the average percentage of protein; i.e., it converts the standard deviation as an estimate of variability into the percentage of the characteristic involved, in this case the protein content. Thus, if the standard deviation of a particular group of analyses is 0.5, and the average protein content is 10 per cent, then the coefficient of variation is 5 per cent.

Owing to the vast number of analyses involved in the eight crops from 1925 to 1932, totaling about 325,000 individual samples, it was not possible to organize all the protein data in this manner. Accordingly, the study was confined to four crops, and to shipments from Minnesota stations. The four crops chosen were 1927, 1930, 1931, and 1932. The first of these seasons, 1927, was the year having the heaviest rainfall, and producing a wheat crop of the next to the highest yield per acre, and the lowest average protein content (11.96 per cent) of any of the 14 seasons included in this study. The crop seasons of 1930, 1931, and 1932 were dry years, 1931 in particular. In the latter season the crop was very light, the weight per bushel was rather low, and the protein content averaged 15.0 per cent. Thus it was insured that different types of wheat crops, grown under different climatic conditions, were included in this phase of the analysis of these data. A total of 18,640 shipments, or an average of 4,660 shipments per year, from an average of 161 shipping points per season, were included in this study. This number should constitute an adequate sample for the computations involved.

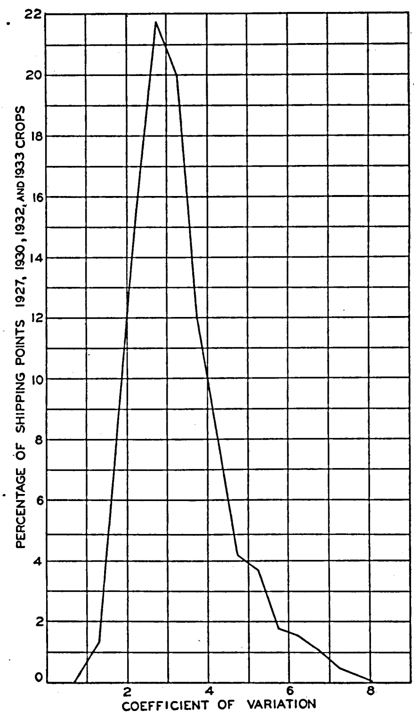

FIG. 22. DISTRIBUTION CURVES SHOWING THE PERCENTAGE OF SHIPPING POINTS THAT FELL INTO EACH CATEGORY WHEN CLASSIFIED ON THE BASIS OF THE COEFFICIENT OF VARIATION OF PROTEIN CONTENT

After the coefficients of variation of the protein content of the shipments from each station were computed, the resulting data were organized into distribution curves similar to that shown in figure 22. These curves recorded graphically the percentage of the total number of shipping points in each season which fell into each category of coefficients of variation, when the latter were grouped in uniform stages with a range of C.V. = 0.5 in each group. Thus all the shipping points with C.V. between 1.01 and 1.50 were included in the first category, those with C.V. between 1.51 and 2.00 in the second category, and so on. The median value of each category was assumed to be the mean.

When the four distribution

curves which represent these data graphically were drawn for the four crops separately, they appeared to be essentially identical, or at least they did not disclose any significant differences from season to season. Accordingly, they are not shown individually in this bulletin, but the average of the four seasons is graphed in figure 22.

The true mean of the coefficients of variation thus recorded graphically is 3.265. Accordingly, it may be assumed that this value, multiplied by the average percentage of protein, would give the average plus and minus deviation from the average protein content of shipments from a single shipping point or station that might be anticipated in individual carloads. Thus, for example, if the average protein content was 13.0 per cent, then the average variation from that value that might be encountered would be 0.42 per cent. This is an appreciable variation and might involve a substantial difference in the market value of the wheat in certain seasons. Obviously, the larger the number of cars of wheat purchased by any one buyer from the same shipping point, the less the average likelihood of losing (or gaining) from variations appearing among individual lots, since the chances are thus increased of balancing minus against plus variations.

PROTEIN PREMIUMS AS A FUNCTION OF PROTEIN CONTENT

Over a period of years it became apparent that the premiums paid for high protein wheat were a function of the general level of protein content of the crop that was being marketed. In seasons of low protein wheat the premiums would mount, whereas when there was an abundance of high protein wheat the protein premiums would tend to disappear. It happened that the first six years of this wheat protein study, from 1925 to 1930, inclusive, included seasons of low and high protein wheat, which was merchandised through a market free from artificial manipulation of protein premiums. Accordingly, an analysis of the effect of the general level of protein content upon the protein premiums was undertaken. One of the large milling companies was kind enough to provide fairly detailed data relating to the premiums paid for each increment of protein during the six years in question. A preliminary analysis showed that there was a general relationship between the average protein content and the protein premiums. Further study indicated that $13 \pm$ per cent of protein appeared to be the critical range which determined the level of premiums. In other words, when much of the wheat contained less than 13 per cent of protein the premiums were high, and vice versa.

The protein data for the six crops beginning with 1925 were then organized on that basis. A graph, depicted in figure 23, was drawn with the percentage of each crop containing over 13 per cent protein recorded on the vertical or Y axis, and the average premium in cents per bushel paid for each 1 per cent protein in the instance of the same crop recorded on the horizontal or X axis. The result is the exponential type of curve at the left of the figure. This discloses that small decreases in the percentage of the crop containing more than 13 per cent protein tended to register an accelerated increase in protein premiums which reached the extremely high level of more than 12 cents for each percentage of protein in the low protein crop of 1927. Also the premium tended to disappear when most of the wheat contained more than 13 per cent protein as in 1930.

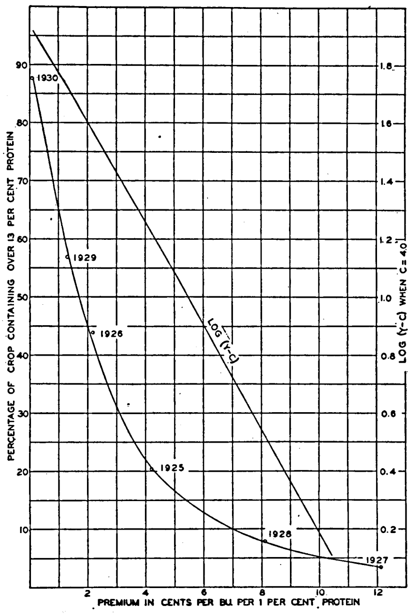

FIG. 23. CURVE AT LEFT SHOWING RELATION BETWEEN PERCENTAGE OF SPRING WHEAT CROP CONTAINING OVER 13 PER CENT PROTEIN (Y) AND PREMIUM IN CENTS PER BUSHEL PER 1 PER CENT PROTEIN (X). GRAPH (STRAIGHT LINE) AT RIGHT SHOWING THE RELATION BETWEEN LOGARITHM OF Y MINUS THE CONSTANT C (= 4.0) PLOTTED AGAINST THE PROTEIN PREMIUM (X)

The data recorded in this first curve were then integrated, and a formula computed to express this relation. This mathematical expression took the form: $\log(y - c) = x$, when y was the percentage of the wheat crop containing more than 13 per cent protein, $x =$ the premium in cents per 1 per cent protein, and c was a constant which proved to be *4.* When the data recorded in the first curve were recalculated using this formula, and the results plotted, they gave the graph appearing as the straight line at the right of the two graphs in figure 23. The fact that this graph is a straight line supports the acceptability of the equation that was computed. Through the use of the graph or that of the formula itself, the probable level of protein premium could be computed from the protein make-up of the crop as thus recorded.

It must be recognized that the general level of protein content of hard spring wheat, as expressed in the percentage which contains more than 13 per cent protein, will not be the sole factor in determining the magnitude of protein premiums. In fact, the protein level of the hard winter wheats grown in the southern reaches of the Great Plains area would be reflected in the relative demand for, and hence the amount of the premiums paid for, high protein spring wheat. Likewise, if there was a large volume of low protein wheat on the West Coast, the millers who were attempting to convert it into bread flours might reach into the hard wheat areas for high protein wheat, which, in turn, would tend to extend the demand for the latter and increase protein premiums. Accordingly, the situation is more complex than is depicted by the formula here presented, or the graph based thereon, and these additional factors, and some others must not be overlooked in attempting a prediction of premiums from the composition of the wheat crop in one restricted area.

SURVEY OF PROTEIN CONTENT OF SOFT WINTER WHEATS

Through the courtesy of the Tri-State Soft Winter Wheat Improvement Association, Toledo, Ohio, in cooperation with the Ohio Agricultural Experiment Station, Wooster, Ohio, and the Federal Soft Wheat Laboratory maintained there by the Bureau of Plant Industry of the United States Department of Agriculture, access was afforded to the card files of data accumulated in their extensive surveys of the soft winter wheats of Ohio, Indiana, and Michigan, and to limited records from Illinois and Kentucky. Their data were not the result of the operations of a grain inspection system, as in the instance of the hard spring wheat survey, but represented a collaborative system of collecting data from the wheat receipts of flour mills. Consequently the numbers of samples involved were not as vast as in the spring wheat studies, but appeared to have been adequate to an analysis of the areas and crops that were covered. Moreover, the states represented in the study are among the heaviest producers of typical soft winter wheat as grown in the central United States.

The cards on which these data were recorded included the moisture content and percentage of crude protein (N x 5.7) of the wheat samples as analyzed. This made it possible to correct all

Table 7. Average Percentages of Protein in Soft Red Winter Wheat

Crop harvested in	Ohio		Illinois		Indiana		Michigan		All red winter wheat		
	No. of samples	Average protein	No. of samples	Average protein	No. of samples	Average protein	No. of samples	Average protein	No. of samples	Average protein	Standard deviation σ
		Per cent		Per cent		Per cent		Per cent		Per cent	
1931	1968	10.31	3	9.75	994	10.19	96	10.18	3061	10.26	0.67
1932	1934	9.82	....	....	1342	9.85	153	9.52	3429	9.82	0.49
1933	2357	10.63	....	....	1296	10.73	145	10.38	3798	10.65	0.69
1934	2527	11.69	....	....	2658	11.53	125	11.22	5310	11.61	0.82
1935	3709	9.72	....	....	1479	10.33	144	9.81	5332	9.89	0.64
1936	2903	9.42	178	10.04	1551	9.56	....	....	4632	9.49	0.49
1937	1789	9.35	396	9.86	1765	9.24	73	8.85	4501*	9.35*	0.59
					Kentucky						
1937	....	....	....	....	478	9.44	....	....	....	....	....

* Including the Kentucky samples.

the protein data to a constant moisture basis, and for this purpose the basis of 15.0 per cent moisture was arbitrarily chosen. All the protein data included in tables 7 and 8 and in figures 24 and 25 were recorded on that basis.

Distribution curves showing graphically the percentage of the crop represented in each protein category were plotted as in the instance of the hard spring wheat samples. Figure 24 records these curves for the seven soft red winter wheat crops from 1931-32[2] to 1937-38, inclusive. Two outstanding differences between these distribution curves and those for the same crops of hard spring wheat are at once apparent when they are compared. The first is the lower median values of protein content, the soft red wheats being nearly 5 per cent lower in that characteristic. Reduced to averages, as recorded in table 7, the soft red winter wheats ranged from 9.35 per cent crude protein as the average of the 1937-38 crop, to 11.61 per cent as the average of the 1934-35 crop. It is quite notable that the soft red winter wheat harvested in these three states in 1936 was not the highest in protein content by any means, whereas the hard spring wheat harvested that year was outstandingly high in protein percentage. Thus the pattern of annual variations in protein content of the soft red winter wheats did not follow that of the hard spring wheats grown in the northern Great Plains area.

The second major difference between these distribution curves for the soft red wheats and those of the hard spring wheats lies in the lower variability of the former, as registered in the standard deviation recorded in the tabulations and evident from a casual inspection of the distribution curves themselves. For ex-

[2] The crop of 1931-32 is the crop that was planted in the fall of 1930, harvested in the summer of 1931, and marketed through the remaining months of 1931 and the early part of 1932.

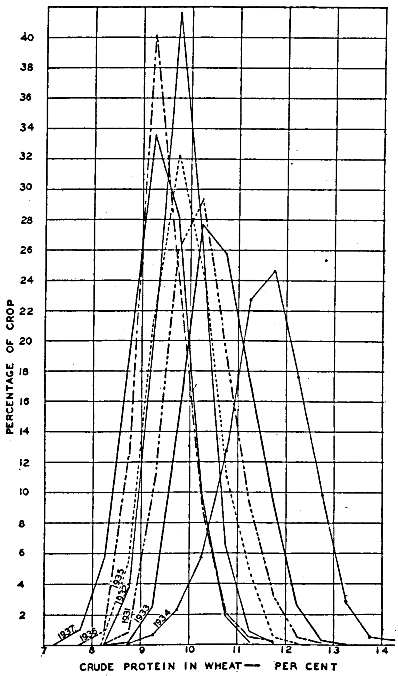

FIG. 24. DISTRIBUTION CURVES SHOWING THE PERCENTAGES OF THE SOFT RED WINTER WHEATS, CROPS OF 1932 TO 1938, THAT FELL INTO EACH PROTEIN CATEGORY

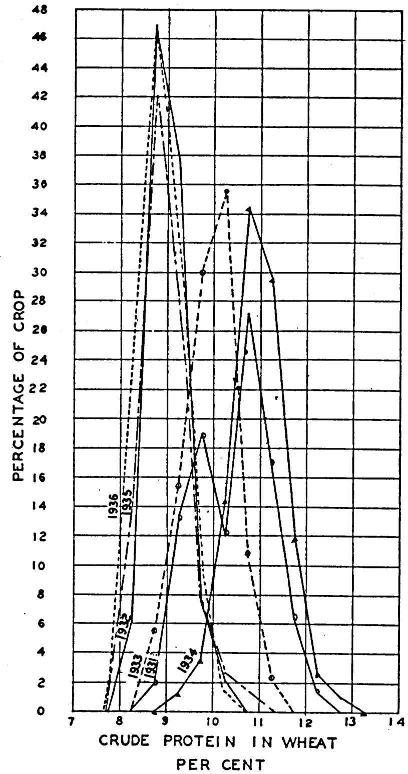

FIG. 25. DISTRIBUTION CURVES SHOWING THE PERCENTAGES OF THE WHITE WHEATS, CROPS OF 1932 TO 1937, THAT FELL INTO EACH PROTEIN CATEGORY

ample, the most prominent or modal category of the 1932 and 1936 soft red winter wheat crops rose to or above the 40 per cent level, with the two adjacent categories at or about 20 per cent. This means that 80 per cent of these crops fell within a range of 1.5 per cent of crude protein. None of the hard spring wheat crops, even during the least variable crops of 1927 and 1928, approached the small variability of these two soft winter wheat

Table 8. Average Percentages of Protein in White Winter Wheat

Crop	Ohio		Indiana		Michigan		All white winter wheat		
	No. of samples	Average protein	No. of samples	Average protein	No. of samples	Average protein	No. of samples	Average protein	Standard Deviation σ
		Per cent		Per cent		Per cent		Per cent	
1931	50	9.70	2	9.75	300	10.54	352	10.30	0.81
1932	95	9.09	...	....	402	9.00	497	9.01	0.41
1933	64	10.58	...	....	243	9.84	307	9.92	0.58
1934	84	10.95	...	....	161	11.32	245	11.19	0.67
1935	175	8.83	...	....	402	9.03	577	8.97	0.54
1936	241	8.98	...	....	284	8.98	525	8.98	0.43

crops. When standard deviation (σ) is used as the criterion of variability, the average value of σ for the seven soft red winter wheat crops from 1931 to 1937 was half that of σ for the same hard spring wheat crops.

On comparing the white winter with the soft red winter wheats, it appears that the six-year average protein content of the white wheats was lowest by 0.42 per cent, and, actually, the average of the protein percentage in all of these individual crops was lower in the white winter wheats except in the one instance of the crop of 1931-32. Whether this is the consequence of a tendency of white wheats as a group to contain less protein, or whether it results from the fact that they were grown in different areas where the climate is conducive to the production of wheat low in protein content is not apparent from the treatment accorded the data in this study. Long time comparative variety tests by the Ohio Station indicate the former to be true insofar as the commonly grown Ohio white wheats are concerned.

Moreover, the change in average protein content of the soft red winter wheats from year to year that has already been noted was paralleled almost exactly by the white winter wheats. The 1934 crop was the highest and the 1935 and 1936 crops the lowest of the six seasons through which such comparisons can be made.

SUMMARY

Distribution curves of protein content of 14 crops of hard spring wheat marketed through Minneapolis, Minnesota, from 1925-26 to 1938-39 are presented. In general it appears that the protein content tends to increase in progressing from the eastern to the western reaches of the spring wheat area, although this was not true in all seasons.

Variability in protein content of spring wheat was not uniform from season to season. Measured as standard deviation, it was greatest in 1935 and 1936, which were also the seasons of highest average protein content, and lowest in 1927 and 1928, when the protein content was also the lowest of the 14 crops.

Rainfall appeared to be prominent among the climatic factors influencing the protein content of a crop. Correlation between rainfall and average protein content was not perfect, however, since there was a carry-over of the effect of previous seasons.

Dark northern spring wheat had a higher average protein content than northern spring in the four seasons when subclass comparisons were made. Protein content of individual lots or samples of the two subclasses, however, overlapped somewhat.

Variability of individual shipments from a single shipping point was measured, and the standard deviation of the coefficient of variation of an average of 161 shipping points per season for four seasons was 1.14. This is interpreted to mean that the chances are even that a single shipment would fall within ± 1.14 per cent of the average protein content for the station. Thus if the average protein content was 15 per cent, the chances are even that an individual shipment would have a protein content between 0.17 per cent less, or 0.17 per cent more than that percentage.

Protein premiums appeared to be a function of the percentage of the crop which contained more than 13 per cent protein. The relation between these two variables is expressed graphically as an exponential curve, which can be resolved into a straight line by using the equation: $\log (y-c) = x$, in which $y =$ percentage of crop containing more than 13 per cent protein, $x =$ protein premium in cents per bushel per 1 per cent protein, and $c =$ a constant, which proved to be 4.

Soft red winter and white wheats grown chiefly in Illinois, Indiana, Ohio, and Michigan during the crop seasons of 1931-32 to 1937-38 contained a lower average percentage of protein than the hard spring wheats harvested during the same seasons.

Variability in the protein content of the samples of soft red winter wheat was only about half as great as the variability among the hard spring wheats.

ACKNOWLEDGMENTS

The author gratefully acknowledges the cooperation and assistance of several agencies and individuals in collecting, organizing and analyzing the data presented in this bulletin, including the State Grain Inspection Department, and its Chief, Mr. M. E. Jerdee; Mr. Fred G. Smith, of the Agricultural Marketing Service, United States Department of Agriculture; the Federal Soft Wheat Laboratory operated cooperatively by the United States Department of Agriculture and the Ohio Agricultural Experiment Station, and Dr. E. G. Bayfield, formerly head of that laboratory, and Dr. C. A. Lamb, Ohio Agricultural Experiment Station; Miss Catherine Harrington who computed numerous of the statistical constants; Mr. Paul P. Merritt who aided in the preparation of the graphs; the Work Projects Administration, its supervisory staff and employees who provided facilities for assembling the hard spring wheat data from the files of the State Grain Inspection Department, and the soft winter wheat data from the records of the Tri-State Soft Winter Wheat Improvement Association.

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